PERFORMANCE OF THE COLLIMATION SYSTEM DURING 2016 - HARDWARE PERSPECTIVE

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Abstract

The commissioning experience of the LHC collimation system in 2016 is reviewed together with the hardware performance. Despite of the limited changes in hardware and software, the time spent in commissioning, set-up and qualification activities has been reduced thanks to system upgrades like the deployment of 100 Hz BLM logging for collimator alignment and detailed commissioning of embedded BPMs. In particular, the reliability and stability shown by embedded BPMs allowed to systematically align TCT collimators and accommodate beam manipulations at the IPs; furthermore, following the gained experience, a proposal of SIS interlock based on the readout of embedded BPMs is made. The LHC collimation system experienced a limited number of faults, which is reported. Hardware changes foreseen for EYETS 2016, mainly dedicated to MD activities, are outlined.

INTRODUCTION

2016 was an unprecedented year of physics production for LHC, with half of machine time spent in stable beams [1], peak luminosity being pushed beyond the nominal value of 10^{34} cm^{-2} s^{-1}s, and total integrated luminosity reaching ∼40 nb^{-1}, surpassing by far the original target of 25 nb^{-1}. The quality of the performance of each LHC system was at the basis of these achievements [2]. Among them, the collimation system performed reliably and accomodated the numerous machine configurations deployed over the year.

The LHC collimation system saw limited hardware and software updates during the Year End Technical Stop of 2015 (YETS 2015), but these were relevant for speeding up commissioning and set-up activities in 2016. Reliability and reproducibility were at the heart of the system performance throughout the year.

HARDWARE CHANGES DURING YETS 2015

The collimation system saw limited hardware changes during YETS 2015, mainly dedicated to the implementation of the "5th motor axis" functionality [3]. This functionality allows to move transversely the whole collimator (including the tank) in the non-cleaning plane by ±10 mm to offer a fresh surface to beam cleaning after a local damage of the jaw.

The necessary hardware changes were applied to the metallic collimators in cell 4 in the high luminosity insertion regions (IRs), i.e. to the tertiary collimators (TCTs) in IR1 and IR5 and the physics debris absorbers nearby (TCL4). The LHC areas where the involved collimators are installed are particularly complicated for intervention [4] (see Fig. 1); in spite of many small problems found during the intervention, it was possible to fully recover the functionality at the horizontal collimators, whereas only half-movement (more precisely, the one inwards) was recovered at the vertical collimators. The intervention was carried out with no impact on machine availability.

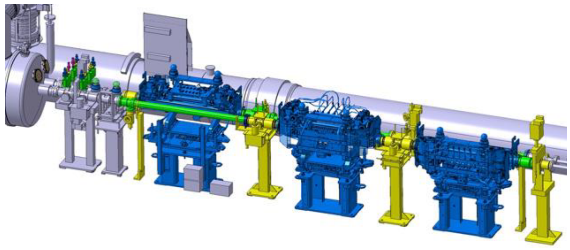

Figure 1: 3D visualisation of one of the areas of intervention.

It should be noted that nowadays the necessity of the 5th axis functionality is less stringent, thanks to the optimesed phase advance between extraction kickers (MKDs) and closest TCT collimators [5].

SYSTEM AVAILABILITY

The operation of the LHC collimation system in 2016 was affected by twelve faults as from the post mortem (PM) database data browser [6]. Half of them occurred at injection energy; two occurred during ramp; one took place at flat top (FT), and three in stable beams (SB). These statistics do not cover beams dumped by BLMs at collimators following UFO events [7]. The breakdown of fault reasons are reported in Tab. 1, sorted by occurrence.

Faults taking place during manual operations mainly refer to machine development (MD) activities and optics measurements, hence when collimators were controlled not by functions coded in the LHC control system. Wrong collimator set-up refers to incorrect or obsolete values in functions of the LHC control system; in particular, faults in 2016 involved only limits to jaw movements left in the control system immediately after the fault of the power converters of the Proton Synchrotron (PS) occurred on the 21st May [8] and after the Van der Meer scans. These functions set tolerances between the expected position of the jaw corners and the actual readout from the Linear Variable Differential Transformer (LVDT) sensors [9]; when tolerances are exceeded, a preventive beam dump is triggered.

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Table 1: Breakdown of causes of faults of the LHC collimation system: number of occurrence, main cause and active beam process when the fault took place. Since half of the faults took place at injection, only those happening during other beam processes are reported in the third column.

#	Cause	Beam Process
5	manual operations	1 at FT
3	related to IR3 flooding	2 in SB
2	wrong collimator set-up	1 in ramp, 1 in SB
2	temperature sensors	1 in ramp

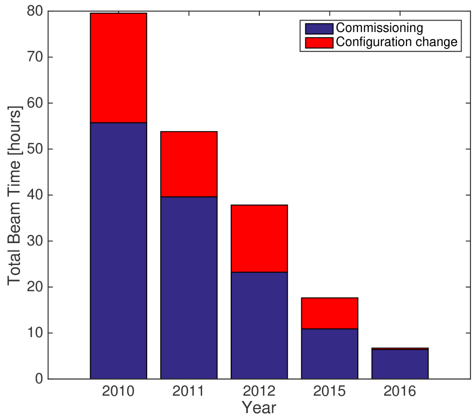

Figure 2: Progress in the time required to align the full collimation system.

Three beam dumps were triggered by collimators in IR3, i.e. fills 5068, 5075 [10] and 5194 [11]. These were the consequence of the water flooding in IR3 that took place on 21[st] June 2016 [12], which involved the false floor of UJ33. During flooding, cables carrying the LVDT signals were in contact with the water; this caused a slow deterioration of the cables, with consequent changes in the inductance of the cables and drifting of signals.

HARDWARE PERFORMANCE

Commissioning

Several changes where done to the collimation software [13]. In particular, changes to several application programming interfaces (APIs) were incorporated in the new release of the Java applications. Moreover, new devices from the ATLAS Forward Proton (AFP) [14] experiment were included in the collimation LSA [15] table and in the Java application. Finally, the names of the crystal goniometer were updated in both the Java application and in the FESA [16] class.

The LHCCollAlign FESA class was updated to handle 100 Hz BLM data, a data stream set-up on purpose. Therefore, it was possible to increase the collimator trigger rate and hence the alignment feedback loop to 50 Hz, considerably shortening the alignment time. In fact, it was possible to align the entire collimation system in 1hr 45min, allowing the continuation of the trend in shortening alignment time

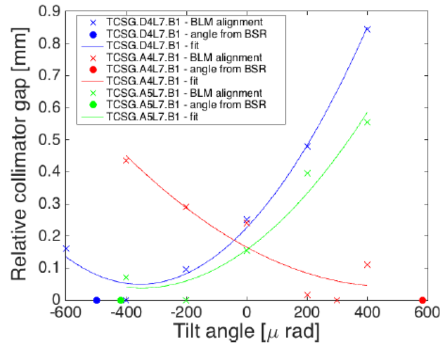

Figure 3: Angular scans at selected secondary collimators.

(see Fig. 3). This was also possible thanks to the full deployment of Beam Position Monitors (BPMs) for collimator alignment. It should be noted that in 2016 the full BLM alignment of all TCTs was anyway performed at injection and flat top, to get the measured beam sizes; the required time is included in the blue bar of the alignment time bar chart. It is planned to update the alignment software with an automated procedure for angular alignments; moreover, a new FESA class is under development to handle the coordination of the alignment of many collimators in parallel, presently handled by the Java application.

Angular scans were performed at selected secondary collimators (see Fig. 3). These revealed the necessity to introduce in future large jaw angles (i.e. in the order of few hundreds of microrad) in order to compensate the apparent angle between the beam closed orbit and the collimator jaw, introduced by e.g. tank misalignments. These tilt angles play a fundamental role in restoring the correct hierarchy between collimator families when the retraction between primary and secondary collimators is pushed down to 1 σ [17].

An exhaustive commissioning of BPMs at collimators was carried out before the alignment campaigns; therefore, it was possible to deploy the automated BPM beam-based alignment of all the tertiary collimators (TCTs) in parallel as much as possible. The commissioning included extensive collimator scans [18] for determining the coefficients for correcting non-linearities in BPM signals. The scans were carried out recording the BPM readout while varying both jaw opening and absolute positions (jaw offset). BPMs were available since the very beginning of the initial commissiong with beam, being up and running for the whole time,save for a couple of instances when the FESA class was down. No issues were reported as of technical stop (TS) 1.

The alignment data at TCTs were used to build time-dependent functions of the collimator centres [19]. These have been obtained scaling the time profile of the closed orbit at each TCT as predicted by MADX to the position of the beam at the beginning and end of each beam process, measured during the alignment campaigns. In particular, BPM beam-based alignment data have been extensively used to generate the functions; BPM readouts during fills preceeding or following the alignmetn have been used to cross-check

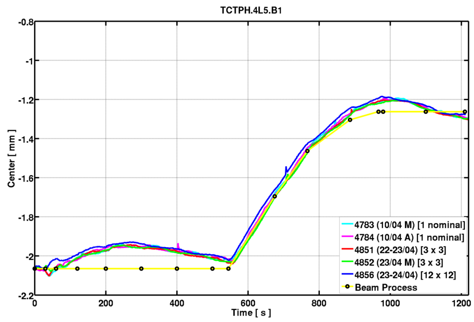

Figure 4: Centre function of TCTPH.4L5.B1 for the ramp and squeeze beam process (yellow dotted line) superimposed to BPM readouts during some fills with different intensities.

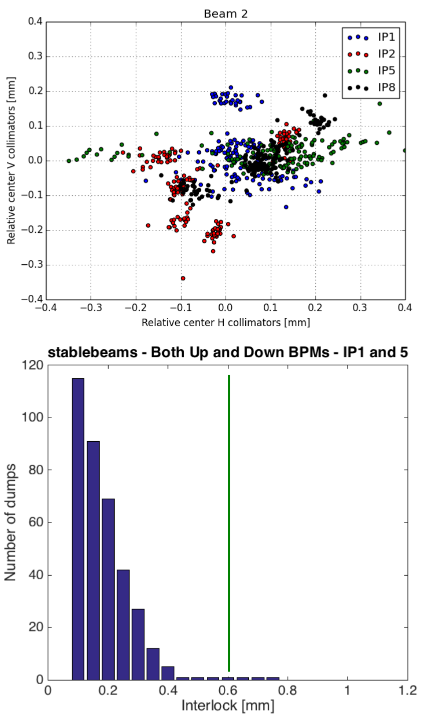

Figure 5: Upper frame: orbit offset with respect to the TCT centre during stable beams; the average between upstream and downstream BPM readouts is shown. Lower frame: estimated number of beam dumps for a given threshold in orbit offset.

the generated functions (see Fig. 4). A function for each TCT in every beam process used in 2016 was generated.

Proposal of SIS Interlock Based on TCT BPM Readouts

The orbit as measured by BPMs at TCTs and at the TCSP collimators in IR6 were monitored throughout the year. In total, 155 fills for proton-proton operation in 2016 in different machine configurations were analysed [20], computing the excursions with respect to the collimator centres. Given the good orbit stability (see Fig. 5), a SIS interlock based on the maximum allowed excursion at the TCT has been proposed. Computing the number of dumps that a given threshold would have triggered in the analysed fills (see Fig. 5), a threshold of 600 μm is proposed.

VALIDATION

Loss maps allow to validate the set-up of the collimators for selected machine configurations. During the period of the initial commissioning with beam, they are measured once final collimator functions have been generated and imported into the LHC control system. Qualification loss maps are systematically performed also after relevant hardware interventions or long periods without beam like a technical stop.

Given the complexity of the LHC hyper-cycle with many beam processes in 2016, several machine configurations had to be qualified, implying to perform and analyse a large number of loss maps. Nevertheless, there was a limited impact in terms of number of fills required, thanks to the development of the new FESA class for off-momentum loss maps [21]. The new class include the handling of an automatic feedback to the RF trim, which is cut in case losses exceed pre-defined values, in advance before the dump is triggered. Some MD time [22] was specifically allocated for the final assessment of using the new class for loss maps.

Symplifying the LHC hypercycle would imply less loss maps to be performed.

HARDWARE CHANGES DURING YETS 2016

Hardware changes foreseen for the Extended Year End Technical Stop 2016 (EYETS 2016) are mainly aimed at MD activities. In particular, new hardware will be installed, namely:

- a low-impedance secondary collimator, i.e. TCSPM.D4R7.B2. This collimator is equipped with jaws in MoGr, characterised by a higher conductance than graphite. Moreover, the surface of the jaw is coated with three different materials in separated stripes, i.e. Mo, MoGr and a ceramic material, so that, following impedance measurements, the choice of the optimum coating can be done. Tests of this collimator with beam are extremely important, for starting the procurement of all the secondary collimators to be exchanged in view of the High Luminosity LHC (HL-LHC) project [23, 24]. The collimator is also equipped with upstream and downstream BPMs embedded in the jaws and a third BPM in the non-cleaning (horizontal, for this specific collimator) plane, which is at a fixed aperture;

- two collimators with wire embedded in the tungsten jaws for long-range beam-beam effects compensation studies, namely TCL.4L5.B2 and TCTPH.4R5.B2. Moreover, these collimators are equipped with BPMs;

- a TCP collimator with a consolidated design, i.e. with BPM buttons. The concerned collimator is TCP.C6L7.B1;
- two crystal goniometers in beam 2.

All the installation activities will be carried out in close collaboration with EN/STI and EN/MME.

CONCLUSIONS

The performance of the collimation system in 2016 has been reviewed. During YETS 2015, the system underwent limited hardware and software upgrades; nevertheless, these have proved to be relevant for speeding up commissioning and set-up activities, e.g. RF trim for off-momentum loss maps, the deployment of 100 Hz BLM data for BLM beam-base alignment, and using BPM data at TCTs.

Over the entire 2016, reliability and reproducibility have been at the heart of system performance. In particular, the orbit stability at the TCT collimators allows to make a proposal of SIS interlock on drifts of the closed orbit.

During EYETS 2016 new hardware will be installed, meant in particular for MD activities, especially in an HL-LHC perspective.

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