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CLEANING PERFORMANCE OF THE LHC COLLIMATION SYSTEM UP TO 4 TeV

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Abstract

In this paper we review the performance of the LHC collimation system during 2012 and compare it with previous years. During 2012, the so-called tight settings were deployed for a better cleaning and improved _⋆ reach. As a result, a record cleaning efficiency below a few 10−4 was achieved in the cold regions where the highest beam losses occur. The cleaning in other cold locations is typically a factor of 10 better. No quenches were observed during regular operation with up to 140 MJ stored beam energy. The system stability during the year, monitored regularly to ensure the system functionality for all machine configurations, and the performance of the alignment tools are also reviewed.

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Abstract

In this paper we review the performance of the LHC collimation system during 2012 and compare it with previous years. During 2012, the so-called tight settings were deployed for a better cleaning and improved $\beta^\star$ reach. As a result, a record cleaning efficiency below a few 10^{-4} was achieved in the cold regions where the highest beam losses occur. The cleaning in other cold locations is typically a factor of 10 better. No quenches were observed during regular operation with up to 140 MJ stored beam energy. The system stability during the year, monitored regularly to ensure the system functionality for all machine configurations, and the performance of the alignment tools are also reviewed.

THE LHC COLLIMATION SYSTEM

The LHC collimation system provides a multi-stage cleaning in two main cleaning insertions, IR3 for momentum cleaning and IR7 for betatron cleaning. The primary collimators (TCPs) are the closest to the beam in transverse normalized space, cutting the primary halo. The secondary collimators (TCSGs) cut the particles scattered by the primaries (secondary halo) and the absorbers (TCLAs) stop the showers from upstream collimators [1]. The tertiary collimators (TCT) protect directly the triplets at the colliding IRs. Together with the passive absorbers, the physics debris absorbers, transfer line collimators, injection and dump protection makes a total of 108 collimators, hundred of them movable that need to be aligned within $10-50\ \mu\mathrm{m}$ precision to achieve the required cleaning.

During the 2012 running period with 4 TeV beam energy the collimator system was setup with the so-called "tight" collimator settings [2], illustrated in Figure 1, where the primary collimators are set to their nominal 7 TeV gaps in mm corresponding to $4.3\ \sigma$ at 4 TeV (assuming normalized transverse emittance of $3.5\ \mu\mathrm{m\,rad}$) and a 2σ retraction for secondaries and absorbers in IP7 is applied with full gaps as small as 2.1 mm. This settings were necessary to achieve smaller $\beta^\star$ down to 0.6 cm at 4 TeV providing more luminosity to the experiments [5–7].

Figure 2 shows the evolution of the collimator settings since 2010, from "relaxed" to "tight" and the nominal collimator settings (black, blue and red line respectively). The figure shows how the settings evolved during the first years of operation of the LHC. The "tight" settings used in 2012 were validated during MD's in 2011 [2–4]. In particular, it was verified that the proposed hierarchy could be achieved without additional alignment campaigns, indicating that the orbit and collimator settings are stable enough to ensure a good hierarchy with $2\ \sigma$ retraction between TCSGs and TCLAs with 1 single alignment per year. Optimization of TCT settings and measurement of the aperture that can be protected are detailed in [8]. The nominal settings are even "tighter" and have been tested during several MD's [3, 16] but up to date they were not used in regular operation.

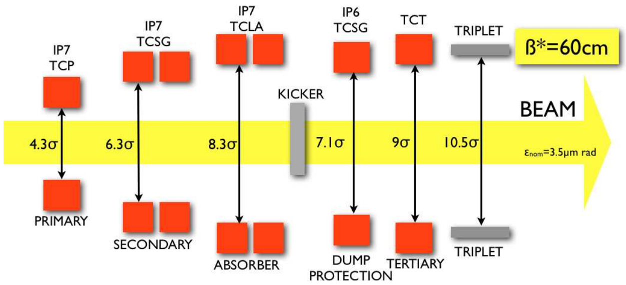

Figure 1: Tight collimator settings for 4 TeV beam energy and $\beta^\star = 60$ cm.

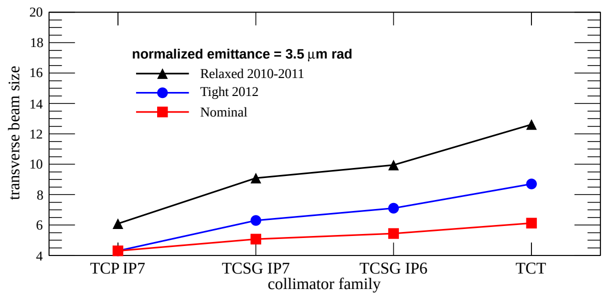

Figure 2: Collimator settings in beam size units at 4 TeV. The TCTs at 2010 were at $15\ \sigma$.

COLLIMATOR ALIGNMENT

All collimators are setup symmetrically around the beam orbit for each machine configuration (*i.e.* injection, flat top, squeeze and collisions). The alignment procedure is used to set each collimator jaw independently around the beam orbit based on the beam loss monitor (BLM) spike observed when touching the beam halo with the primary collimators. This is done only in dedicated low intensity fills with up to 3 nominal bunches which is the safe limit to mask a subset of beam interlocks like collimator positions and BLMs.

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The operational strategy during 2011 and 2012 run periods was to perform one full alignment of the main cleaning insertions (IR3 and IR7) and monitor regularly the losses along the ring to validate if a new alignment was needed by looking at the cleaning and the collimator hierarchy versus time. For new physics configurations only the 16 TCTs collimators at the colliding IRs need to be re-aligned. This strategy proved to be successful thanks to the excellent machine (orbit, optics, etc.) and collimator settings stability, only one alignment was required in IR3, IR6 and IR7.

Since 2010 several improvements have been implemented in the alignment software towards a faster, more reproducible and human-error proof alignment [9–13]. The main improvement on the alignment speed was the use of the 12.5 Hz BLM data, available from the start of 2012 run. This allowed to use the maximum collimator movement rate of 8 Hz that before was limited by the 1 Hz BLM data. In addition, currently, it is possible to align in parallel several collimators and the algorithm automatically identifies the loss spike and decides if the collimator is completely aligned. Figure 3 shows the setup time per collimator as function of time. Nowadays, all collimators in IR7 (19 collimators per beam) and IR6 (2 collimators per beam), a total of 42 collimators, can be re-aligned in about 50 min [1]. Ever since the semi-automatic alignment was set in place, no more beam dumps at top energy happened during alignments [13].

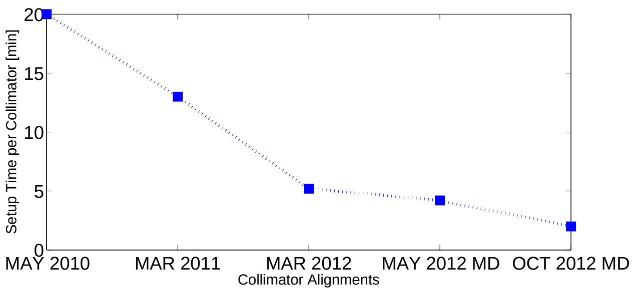

Figure 3: Setup time per collimator versus alignment date.

SYSTEM PERFORMANCE

In order to validate the cleaning hierarchy and study the performance of the collimator system, loss maps are performed. Beam losses are recorded along the ring while exciting the beam with the transverse damper (ADT) [14] and are compared with the peak losses at the primary collimators to compute the cleaning inefficiency. The ADT introduces white noise in vertical or horizontal plane that can be gated to selected bunches. When the ADT is working on this mode the excited bunch is blown up with a controlled speed and interacts with the collimators producing beam losses along the ring that simulate what would happen in case of instabilities. Figure 4 shows the losses for Beam 1 (beam is going from left to right) blown up in the horizontal plane. The highest peak occurs at the betatron cleaning insertion (IR7). The cleaning inefficiency is defined as the

[1]This relies on having a good approximation of the beam centers.

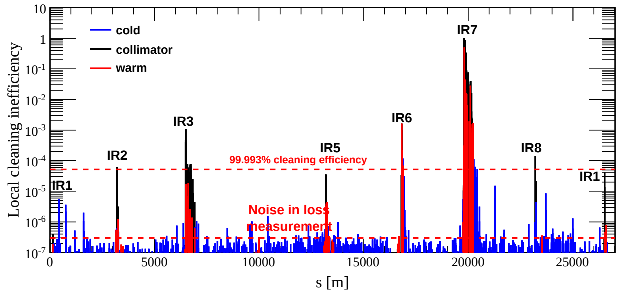

Figure 4: Distribution of the losses in the LHC ring while exciting Beam 1 in the horizontal plane.

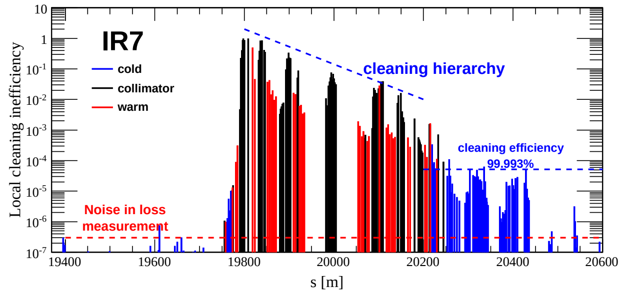

Figure 5: Distribution of the losses in the betatron cleaning insertion (IR7) while exciting Beam 1 in the horizontal plane.

highest leakage at the cold magnets, which is in the dispersion suppressor region of IR7.

In this analysis, the cleaning is approximated by dividing each BLM signal by the highest loss at the primary collimator. Figure 5 shows a zoom into IR7, the cleaning hierarchy appears as decreasing losses from the primary collimators (left IR7) to the absorbers (right IR7). The limiting location for cleaning is the element that would quench first in case of collimation losses, in this case is the Q8 magnet, right of IR7.

Off-momentum cleaning in IR3 is also validated by looking at losses artificially generated by changing the LHC radio frequency (RF) by ± 500 Hz in order to generate an off-momentum shift big enough to measure the cleaning inefficiency in IR3. Figure 6 and 7 show the cleaning inefficiency for this type of losses. Notice that the highest loss occurs now in IR3 as opposed to the betatron losses were the peak appears in IR7. Typically the off-momentum cleaning inefficiency is about 10^{-4}. The losses peak at both TCPs (Beam 1 and 2) because the RF is coupled to the two beams.

The local betatron cleaning inefficiency from 2010 to 2012 is shown in Figure 8. In 2010 and 2011 the beam energy was 3.5 TeV and the relaxed collimator settings were used [15] while in 2012 the beam energy was increased to 4 TeV and the tighter collimators settings described in previous section were used. The figure shows an excellent stability of the cleaning performance which was achieved with only one alignment campaign per year at the beginning of each run period. In 2012, with the “tight” settings the average cleaning improved from 99.97 % to 99.993 % with

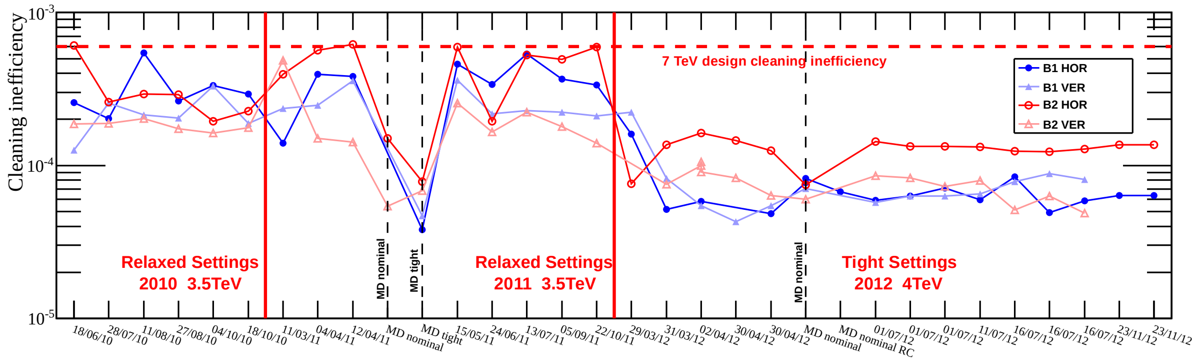

Figure 8: Collimation cleaning inefficiency as function of time since 2010 until end of 2012 run.

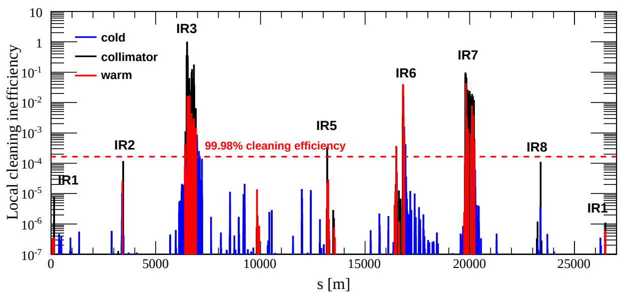

Figure 6: Distribution of the losses in the LHC ring for a negative off-momentum loss map.

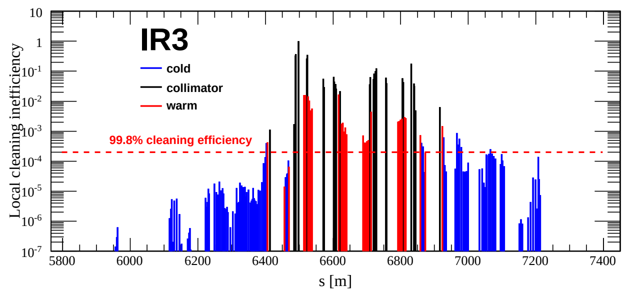

Figure 7: Distribution of the losses in the momentum cleaning insertion (IR3) for a negative off-momentum loss map.

small dependence on the beam energy [17]. This was observed also during a machine development test in 2011 [3] which is included in the figure. We observe little dependence on energy.

CONCLUSIONS

The performance of the collimation system was discussed. The improvements on the alignment tool decreased the collimation setup time from 20 min to few minutes per collimator. The cleaning stability in the dispersion suppressor region of IR7 along the LHC running periods was analyzed and was shown to be excellent. In 2012, with the "tight" collimator settings the average cleaning inefficiency (η_c) at Q8 in IR7 was about $\eta_c = 7 \cdot 10^{-5}$ for Beam 1 (both horizontal and vertical halo cleaning) and Beam 2 vertical and around $\eta_c = 10^{-4}$ for Beam 2 horizontal. Even though not required for cleaning, this improvement was crucial to push for $\beta^\star = 0.6$ cm. No quenches with circulating beams were experienced with up to 140 MJ at 4 TeV.

ACKNOWLEDGMENT

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