Tests of tight collimator settings in the LHC


Keywords: LHC, collimation

Summary

During this MD, performed on November 5th 2011, we have tested tight collimator settings in the LHC, using the centers from a beam-based setup in March 2011. The IR7 and IR6 collimators were driven to tight settings during the energy ramp using smooth functions and, after a squeeze to $\beta^* = 1$ m, the TCTs were moved in to 9.3 $\sigma$. In this configuration, the cleaning performance was assessed through loss maps, which showed a good cleaning hierarchy. However, during the ramp and squeeze, beam losses were observed, as orbit oscillations caused beam to be scraped off at the primary collimators. Nevertheless, the results of this MD shows an excellent long-term stability of the cleaning hierarchy.

1 Introduction

Tight collimator settings were first tested in an MD on May 7th 2011 [1] as a fall-back solution when nominal collimator settings, as defined in the LHC design report, showed evidence of a broken cleaning hierarchy. Tight settings were then further tested in an end-of-fill study on August 21st [2], and in an MD on August 29th [3]. The tight settings keep the primary collimator (TCP) at the same setting in mm as for nominal settings at 7 TeV, but the other collimators are kept at larger retractions. The settings in $\sigma$, calculated using a normalized emittance of 3.5 $\mu$m and the local $\beta$-function at the collimator, are shown in Table 1. For comparison, the relaxed settings used routinely during physics operation in 2011 are also shown.

Operational experience with tight settings is valuable for future operation since the setting of the TCP in mm is similar to the nominal 7 TeV setting. Furthermore, the tight settings have shown an increase in the cleaning efficiency by a factor 3–10 compared to the intermediate settings [1, 3]. This allows a larger beam intensity to be safely stored in the LHC. Another advantage with tight settings is that a smaller aperture in units of $\sigma$ can be protected, since all collimators are closer to the beam. This allows for a smaller $\beta^*$ in the interaction points (IPs) and thus a higher luminosity [4].
The main aim of the MD was to investigate the long-term stability of the cleaning performance with tight settings. Most collimators were not aligned around the center found with a beam-based calibration after the setup in March 2011. Therefore it is valuable to assess the cleaning performance several months later and show that the system can be kept running for longer times without major intermediate setups.

A second purpose of the MD was to qualify the cleaning using the ATS optics [5, 6] with $\beta^* = 40$ cm for future studies with high pile-up. Unfortunately this could not be achieved, since the wanted optics was not yet fully commissioned by the time of the MD due to downtime of the LHC. Instead, the same $\beta^* = 1$ m optics was used as in the physics runs in the last part of 2011 [7].

## 2 Machine conditions

One nominal bunch per beam was injected and ramped to 3.5 TeV. The injection was carried out using the standard collimator settings, while the collimators in IR7 and IR6 were driven to the tight settings given in Table 1 during the ramp using smooth functions. The IR3 collimators and the TCTs were moved in to their standard physics settings. The centers from previous setups (March 8th 2011 in most cases) were used and only the gap opening changed. The emittances were measured at flat top with values given in Table 2.

<table>
<thead>
<tr>
<th>Collimators</th>
<th>Relaxed setting ($\sigma$)</th>
<th>Tight setting ($\sigma$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCP IR7</td>
<td>5.7</td>
<td>4.0</td>
</tr>
<tr>
<td>TCS IR7</td>
<td>8.5</td>
<td>6.0</td>
</tr>
<tr>
<td>TCL IR7</td>
<td>17.7</td>
<td>8.0</td>
</tr>
<tr>
<td>TCP IR3</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>TCS IR3</td>
<td>15.6</td>
<td>15.6</td>
</tr>
<tr>
<td>TCL IR3</td>
<td>17.6</td>
<td>17.6</td>
</tr>
<tr>
<td>TCT</td>
<td>11.8</td>
<td>9.3</td>
</tr>
<tr>
<td>TCS IR6</td>
<td>9.3</td>
<td>6.8</td>
</tr>
<tr>
<td>TCDQ IR6</td>
<td>9.8</td>
<td>7.3</td>
</tr>
</tbody>
</table>

A squeeze to $\beta^* = 1.0$ m was then performed and the half crossing angle reduced to 120 $\mu$rad as in the last part of the 2011 physics run. This corresponds approximately to a $9.3 \sigma$ beam-beam separation in the drift space for a normalized emittance $\epsilon_n = 2.5 \mu$m.
During the ramp and squeeze, significant beam losses were observed. These losses were triggered by orbit movements which caused some beam to be scraped off at the gaps of the primary collimators. Fig. 1 shows the $\beta$-function going down in IP1 and IP5 during the squeeze as well as the beam intensity and the beam loss monitor (BLM) signal at the primary collimator in beam 1 during the same time interval. As can be seen, about 5% of the total intensity was lost in beam 1 (the worst case) and the losses are well correlated with the BLM signal.

Clearly, physics operation cannot be performed with these level of losses and a solution has to be found before the tight settings can be used with high-intensity beams. Such a solution, based on an improved orbit feedback during ramp and squeeze, is under study [8].

3 Loss maps

Once the squeeze was finished at $\beta^* = 1$ m, with the parallel separation still kept on, loss maps were performed. First betatron loss maps were done by provoking losses through a crossing of the third order resonance in the order B1 horizontal, B1 vertical, B2 horizontal and B2 vertical. The loss maps are shown in Figs. 2 and 3, with zooms in IR7 in Figs. 4 and 5. All losses are normalized to the highest loss (primary collimator in IR7) and the background has been subtracted.

The highest measured inefficiencies in the cold regions downstream of IR7 are shown in Table 3, together with the element of the measurement. As in previous MDs, the observed losses in Q5 downstream of IR7 were higher than in the routinely performed loss maps with relaxed collimator settings. However, since these signals are likely to be induced by upstream showers, they have been excluded in Table 3. On the contrary, we have included the losses in Q7, which were previously deselected. Although this loss could be at least partly caused by showers, the inclusion is motivated by the fact that the BLMs in Q7 have the same dump threshold as other downstream BLMs and therefore constitute a similar upper limitation for the intensity.

Table 3: The highest obtained local cleaning inefficiencies and the corresponding machine elements downstream of IR7 for both beams and planes. The losses in Q5 have been excluded as they are likely caused by showers from nearby collimators.

<table>
<thead>
<tr>
<th>B1 hor</th>
<th>B1 ver</th>
<th>B2 hor</th>
<th>B2 ver</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q7R7</td>
<td>7.2E-05</td>
<td>Q7R7</td>
<td>6.9E-05</td>
</tr>
<tr>
<td>Q8R7</td>
<td>3.8E-05</td>
<td>Q9R7</td>
<td>4.1E-05</td>
</tr>
<tr>
<td>Q11R7</td>
<td>3.5E-05</td>
<td>Q11R7</td>
<td>3.9E-05</td>
</tr>
<tr>
<td>Q9R7</td>
<td>3.3E-05</td>
<td>Q8R7</td>
<td>3.8E-05</td>
</tr>
</tbody>
</table>

All loss maps show a satisfactory cleaning hierarchy for operation, although the height of the loss signals at secondary collimators in beam 2 are about as high as at the primary collimators. This is a sign that the loss pattern inside IR7 is slightly degraded for beam 2 compared to after a fresh collimation setup and may stem from machine drifts after the
Figure 1: The $\beta$-function at IP1 and IP5 [top], the intensity in B1 (red) and B2 (blue) [middle], and the BLM signal at the primary collimator in B1 [bottom] as a function of time during the squeeze. The starting time of the squeeze is November 4th, 00:21:13 (local time).
collimation setup in March was performed. This was seen also in the previous MD [3] and has not degraded since then.

Compared to previous MDs, where loss maps were performed with tight settings [1, 3], the inefficiencies are comparable but overall an improvement of up to 20% was observed in this MD (if the Q7 is excluded for the sake of comparison). The only exception is beam 2 horizontal, which is slightly worse. This is also where the overall highest cleaning inefficiency was measured. Furthermore, the loss peak in the Q11 is also much higher than with relaxed settings. In beam 1 horizontal plane, the losses were found higher in the Q8 than in Q11 in this MD and the one in August [3], while they were found to be higher in Q11 in May [1].

Compared to the relaxed settings, an improvement of up to a factor 10 can be seen as in previous MDs. The agreement with the previous MDs confirms the assumptions used previously to estimate the intensity reach in the LHC [9, 10, 11].

4 Conclusion

We have described the qualification of tight collimator settings with $\beta^* = 1.0 \text{ m and } 120 \mu\text{rad}$ half crossing angle. The tight settings were introduced through smooth functions in the ramp. During the squeeze, significant losses were observed—in particular, beam 1 lost 5% of the total intensity. The explanation of the losses were orbit oscillations that caused beam to be scraped off at the collimator. A solution through a better orbit feedback is under development in OP [8].

The tight settings were qualified through loss maps (crossing the third order resonance to provoke beam losses). A slight degradation of the loss pattern was visible in IR7 for beam 2, which is a consequence of the machine drifts over time and the smaller margins between the different collimator families. In spite of this, the loss maps still indicate a satisfactory cleaning performance, which in many cases is even slightly better than in the previous MDs.

The collimator centers from previous beam-based alignments of the collimators were kept. In most cases the last alignment was done in March 2011, 8 months before this MD. Our results therefore demonstrate an excellent long-term stability of the cleaning performance with tight settings and the possibility of running the collimation system over long timescales without intermediate collimator setups.

We could not test the tight collimator settings together with the ATS optics and $\beta^* = 40 \text{ cm}$ since this optics had not been commissioned on time for this MD due previous down time of the machine. This is left as a future MD for 2012.

5 Acknowledgements

We would like to thank the OP crew for their assistance during the MD.

References


Figure 2: Losses around the ring, for the two planes in beam 1, in collimators and cold and warm elements during the crossing of the third order resonance.
Figure 3: Losses around the ring, for the two planes in beam 2, in collimators and cold and warm elements during the crossing of the third order resonance.
Figure 4: Losses in the cleaning insertion IR7, for the two planes in beam 1, in collimators and cold and warm elements during the crossing of the third order resonance.
Figure 5: Losses in the cleaning insertion IR7, for the two planes in beam 2, in collimators and cold and warm elements during the crossing of the third order resonance.
Figure 6: Losses in the IR1, for the two planes in beam 1, in collimators and cold and warm elements during the crossing of the third order resonance.
Figure 7: Losses in IR1, for the two planes in beam 2, in collimators and cold and warm elements during the crossing of the third order resonance.
Figure 8: Losses in the IR5, for the two planes in beam 1, in collimators and cold and warm elements during the crossing of the third order resonance.
Figure 9: Losses in IR5, for the two planes in beam 2, in collimators and cold and warm elements during the crossing of the third order resonance.