90 m OPTICS COMMISSIONING

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Abstract

Special $\beta_\mathrm{e} = 90$ m optics have been developed for the two very high luminosity insertions of the LHC [1] [2], as a first step to allow for very low angle precision measurements of the proton-proton collisions in the LHC. These optics were developed to be compatible with the standard LHC injection and ramp optics. The target value of $\beta_\mathrm{e} = 90$ m is reached by an un-squeeze from the injection $\beta_\mathrm{e} = 11$ m. We report about the implementation of this optics and the first experience gained in commissioning with beam.
Abstract

Special $\beta^* = 90$ m optics have been developed for the two very high luminosity insertions of the LHC [1] [2], as a first step to allow for very low angle precision measurements of the proton-proton collisions in the LHC. These optics were developed to be compatible with the standard LHC injection and ramp optics. The target value of $\beta^* = 90$ m is reached by an un-squeeze from the injection $\beta^* = 11$ m. We report about the implementation of this optics and the first experience gained in commissioning with beam.

INTRODUCTION

High-$\beta^*$ optics with $\beta^* > 1000$ m have been requested by the ATLAS-ALFA and TOTEM experiments to allow for very low angle precision measurements of the proton-proton scattering in the LHC using Roman Pot detectors installed in the very forward region around the LHC interaction points IP1 and IP5. We report here about the first experience with the commissioning of the 90 m optics. This is important both for the machine to see how these optics can be efficiently implemented in the LHC as well as for the experiments to allow for first very forward proton-proton scattering data at LHC energies.

The target value of $\beta^* = 90$ m is reached by an un-squeeze from the injection $\beta^* = 11$ m using 17 intermediate steps.

UN-SQUEEZE

The un-squeeze from the injection $\beta^* = 11$ m to $\beta^* = 90$ m results in a significant tune reduction of up to 0.45. It is compensated by an increase of the strength of the main LHC quadrupoles (QD, QF). The validity of this approach was demonstrated in a first test performed in May 2011. As illustrated in Fig. 1, it was possible to reach $\beta^* = 90$ m without any significant beam losses.

To keep matters simple and minimize the risk of damage in case of uncontrolled beam loss, the first study was performed using single bunches of rather low intensity in each of the LHC proton rings, placed such that they would not collide in the interaction regions. This worked very well. The beam intensity was closed to $1.2 \times 10^{10}$ protons for both beams. Feedbacks were used to automatically correct orbits and tunes. Linear interpolation is used for the magnet strength between the steps. The tune distortions introduced by the linear interpolation were calculated. The calculated corrections reach values up to 0.006 between the steps and can be corrected using the LHC trim quadrupoles. To test the procedure, the calculated corrections were only applied for beam 1.

The time evolution of the orbit and tune trims during the first un-squeeze study are shown in Fig. 2.

The tune evolution for beam 1 is rather flat which shows, that the tune excursion between the un-squeeze steps was well predicted and corrected while these excursions are visible for beam 2 and compensated by tune feedback. The orbit and tune corrections found in the first un-squeeze were incorporated as correction for the second un-squeeze illustrated in Fig. 3.

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Figure 1: intensities, energy and $\beta^*$ as a function of time during the first un-squeeze.

Figure 2: Time evolution of orbit and tune trims

Figure 3: intensities, energy and $\beta^*$ as a function of time during the second un-squeeze.
In the second study, beams were injected in the same buckets in beam 1 and beam 2 of the LHC to allow for collisions. This requires beam separation at the interaction points to avoid collisions during the injection and unsqueeze. The separation is provided by closed orbit bumps in the interactions regions which keep the beams transversely separated by at least $\pm 5 \sigma$. The intensity in the second study was increased to $3 \times 10^{10}$ protons.

**OPTICS MEASUREMENTS**

Optics measurements are an important part of the commissioning for two different reasons: the first is to make sure the optics is overall sufficiently well known and corrected and the second to obtain a good knowledge of $\beta^*$ and the optics parameters between the interaction point and the roman pot detectors of the experiments.

### $\beta$ beating

This was measured at three steps: 11 m, 30 m and 90 m. The evolution of the $\beta$-beating is shown in Fig. 4.

**Figure 4: Evolution of the beta-beat during the un-squeeze for beam2**

It shows that there is no major anomaly and that the unsqueeze behaves basically as expected. The peak value for $\beta$ beat is 25% for beam1 in the horizontal plane and 20% in vertical plane. For beam2 the peak value is close to 30%.

### coupling

The standard LHC tunes which are also used here are $Q_x = 64.31$ and $Q_y = 59.32$ which is close to the coupling resonance and requires a good tune and coupling control. The technique used to calculate the local corrections at IP1, IP2, IP5 and IP8 is called segment by segment technique and described in [3]. The local corrections applied on the quadrupoles are summarized in table 1

**Table 1: Summary of local corrections**

<table>
<thead>
<tr>
<th>Corrector</th>
<th>Strength (m)</th>
<th>Corrector</th>
<th>Strength (m)</th>
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<tbody>
<tr>
<td>kqsx3.l1</td>
<td>0.0008</td>
<td>kqsx3.l5</td>
<td>0.0006</td>
</tr>
<tr>
<td>kqsx3.r1</td>
<td>0.0008</td>
<td>kqsx3.r5</td>
<td>0.0006</td>
</tr>
<tr>
<td>kqsx3.l2</td>
<td>-0.0009</td>
<td>kqsx3.r8</td>
<td>-0.0007</td>
</tr>
<tr>
<td>kqsx3.r2</td>
<td>-0.0009</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5: Measured coupling for Beam1 for $\beta^* = 90$ m**

**dispersion**

The technique to measure dispersion is to use a turn-by-turn data acquisition with an energy offset $(\frac{dp}{p})_{B1} = -0.4076$ and $(\frac{dp}{p})_{B2} = -0.394$. Fig. 7 and Fig. 8 shows the difference between the measured and predicted dispersion for beam1 and beam2.

Then K-modulation [4] was used to calculate the $\beta^*$ and the waist for both IPs.

### emittance measurement

The emittances values have been measured using the Wire-Scanners and are summarized in table 2

The emittances were found to be all below the target values (of 3.75 $\mu$m) which is useful for the experiments.

**Figure 6: Measured coupling for Beam2 for $\beta^* = 90$ m**
Figure 7: difference between predicted and measured vertical dispersion function for Beam1.

Figure 8: difference between predicted and measured vertical dispersion function for Beam2.

Figure 9: Calculated parallel separation bumps from $\beta^* = 11$ m to 90 m. The horizontal separation in IP1 is shown on the top and the vertical separation in IP5 in the bottom figure.

SEPARATION BUMPS

To separate the two LHC beams, three types of different corrector magnets are used: MCBC, MCBY and MCBX. The shape of these bumps is shown in Fig. 9.

The separation bumps were calculate to provide a constant parallel separation of $\pm 2$ mm between beam1 and beam2 at IP1 and IP5. Since the optics changes during the un-squeeze and since IP1 and IP5 generally use separation in opposite planes, this required the separated calculation of separation bumps for every step separately for IP1 and IP5.

ACKNOWLEDGMENT

Thanks to M. Deile and al. for TOTEM and P. Fassnacht and al. for ATLAS-ALFA.

Table 2: Summary of local corrections

<table>
<thead>
<tr>
<th></th>
<th>$\epsilon_N$ ($\mu$m)</th>
<th>$\epsilon_N$ ($\mu$m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam1,x</td>
<td>2.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Beam1,y</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Beam2,x</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Beam2,y</td>
<td>2.4</td>
<td>1.8</td>
</tr>
</tbody>
</table>

CONCLUSION

The commissioning of the 90 m $\beta^*$ optics went very well. Beams were un-squeezed without any significant losses and first collisions could already be provided to the experiments at the end of the second study with beams. The experience gained with the 90 m commissioning is essential both for the machine to see how these optics can be efficiently implemented in the LHC as well as for the experiments to provide for first very forward proton-proton scattering data at LHC energies.

REFERENCES