OBSERVATIONS OF TWO-BEAM INSTABILITIES DURING THE 2012 LHC PHYSICS RUN

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Abstract

During the 2012 run transverse coherent beam instabilities have been observed in the LHC at 4 TeV, during the betatron squeeze and in collision for special filling patterns. Several studies to characterize these instabilities have been carried out during operation and in special dedicated experiments. In this paper we summarize the observations collected for different machine parameters and the present understanding of the origin of these instabilities.

INTRODUCTION

The 2012 run of the Large Hadron Collider (LHC) has shown, despite the great physics discovery of a Higgs-like boson, several instabilities which have perturbed the accelerator performances. To achieve the required integrated luminosity several parameters had been changed and pushed compared to 2011: reduced \( \beta^* \) operation (from 1 m to 0.6 m) and higher brightness beams (approximately two times larger than nominal). To ensure protection collimator gaps have been reduced to tight settings with apertures close the nominal 7 TeV configuration leading to larger impedances [1]. A first type of instabilities [2] occurred during stable beams after many hours of physics and affected specific bunches colliding only in the LHCb experiment. In this paper we will focus on instabilities developing at the end of the betatron squeeze and while bringing the beams into collision. The origin of the instability is still not understood however some observations have led to considerations on the beam stability to help defining possible future scenarios. There were several other observations which need further studies and analysis will not be covered in this paper but be found in [3].

END OF SQUEEZE INSTABILITY

In 2012 the LHC peak luminosity has been more than doubled as compared to 2011. The main beam parameters, compared to those of 2010 and 2011, are in Table 1.

The LHC beams were accelerated in 2012 from injection energy (450 GeV) to top energy 4 TeV then the \( \beta^* \) functions at the different Interaction Points (IPs) squeezed (from 10 m to 3 m in IP2 and IP8 and further down to 0.6 m in IP1 and IP5). This process lasts around 15 min and is called the \( \beta \) squeeze. At the beginning of the year during the betatron squeeze at a value of \( \beta^* \approx 1.5 \) m several bunches were becoming unstable loosing intensity in a non reproducible manner. In particular the instability was not present in all physics fills. The bunches were unstable one after the other for several minutes till the head-on collision was established. For some fills the instability was generating very high losses causing a beam dump. Another important parameter for stability is chromaticity which might explain the non reproducibility of the instability when operating close to zero value (LHC was operating at \( Q' \approx 2 \) units till the beginning of August 2012). At the beginning of August 2012 the machine configuration has been changed drastically in terms of chromaticity (changed from 2 units to 15 units [4]), the polarity of the Landau octupoles (changed from negative to positive [5]) and the transverse damper (to 50 turns). The changes have been implemented from Fill 2926 but not always at the same time to distinguish the implications of the three parameters. As a result of these changes the instability has showed important aspects: it became reproducible always occurring after two minutes from the end of the squeeze and has changed to the vertical plane. An example of the bunch by bunch intensity losses versus time during this type of instability is shown in Fig. 1.

The coherent mode is shown in Fig. 2 where several frequencies are visible all spaced by \( Q_s \approx 0.002 \), the synchrotron tune. Several bunches were loosing up to half their intensity while coherently oscillating. Bunches where going unstable at different moments and the instability could last till the head-on collision was established and coherent motion stopped.

The stability of beams before going into the \( \beta \) squeeze is given by the Landau octupoles which ensure a given stability area under which all impedance driven modes should be damped. For the specific case of the LHC the stability region is shown in Fig. 3 (dashed lines). In red we show the stability area with negative octupole polarity and in blue the positive polarity effect. The negative polarity was pre-

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>Nominal</th>
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<tbody>
<tr>
<td>( N_p ) (10^{11} \text{ p/b})</td>
<td>1.2</td>
<td>1.45</td>
<td>1.58</td>
<td>1.15</td>
</tr>
<tr>
<td>( N_b )</td>
<td>368</td>
<td>1380</td>
<td>1380</td>
<td>2808</td>
</tr>
<tr>
<td>Spacing (ns)</td>
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<td>75/50</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>( \epsilon ) (\mu\text{mrad})</td>
<td>2.4-4</td>
<td>1.9-2.4</td>
<td>2.2-2.5</td>
<td>3.75</td>
</tr>
<tr>
<td>( \beta^* ) (m)</td>
<td>3.5</td>
<td>1.5-1</td>
<td>0.6</td>
<td>0.55</td>
</tr>
<tr>
<td>( L ) (10^{32} \text{ cm}^2\text{s}^{-1})</td>
<td>2</td>
<td>35</td>
<td>76</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 1: LHC Operational Parameters
Figure 1: Bunch by bunch losses in beam 1 during an end of squeeze instability as a function of time for Fill 2648 with negative octupole polarity (top picture) and Fill 3250 with positive polarity (bottom plot).

Figure 2: Beam vertical frequency spectrum as a function of time during an end of squeeze instability.

Figure 3: Beam stability diagrams for the two LHC octupole configurations: positive (blue lines) and negative (red lines) before the betatron squeeze (dashed lines) and at the end with long-range contribution (solid lines).

Figure 4: Oscillation amplitude of beam 1 during the collapse of the separation bumps as a function of time.

GOING INTO COLLISION

The end of squeeze instability, as shown in Fig. 2, was lasting also during the collision beam process. At the beginning of the year the process was long (≈ 200 s) and was not directly going for head-on collisions in IP1 and IP5 but JACoW — cc Creative Commons Attribution 3.0 (CC-BY-3.0)
ity. Observations have also demonstrated that the only cure to this instability is the head-on collision which gives the largest possible stability area. To use this important property of the opposite beam several tests have been carried out to allow for the future operation of the machine collisions before the \( \beta \) squeeze [8].

Figure 5: Footprint evolution during separation collapse in both planes synchronously (upper) and only in the horizontal plane (lower).

However to guarantee a stronger stability several configurations have been tested with simulations and have shown that a synchronous collapse of both horizontal and vertical plane separation will lead to a minimum (magenta dots) of stability in both planes at the same time, as shown in Fig. 5 upper plot, where we show the beam footprint for different beam separations equal in both planes. The lower plot shows how one can avoid this minimum by just collapsing one plane at the time. The stability for this second configuration has been studied for both cases and results from multi-particle tracking simulations are shown in Fig. 6. The figure shows the amplitude of oscillation as a function of time for the different separations at the interaction point in both horizontal and vertical plane (upper) and for only the horizontal plane (lower).

The instabilities were mainly occurring at the end of the \( \beta \) squeeze and in the collision beam process. They have changed during the year as a consequence of changed parameters (\( Q’ \), octupoles currents and polarity and transverse damper gain). The origin of the instabilities is not understood yet however counter measures to have more stability are described for the different beam processes.

**REFERENCES**

[1] B. Salvachua et al., “Cleaning Performance of the LHC Collimation System up to 4TeV”, MOPWO048 these proceedings.


[8] X. Buffat et al., “Colliding during the squeeze and \( \beta^* \) leveling in the LHC”, TUPFI033 These Proceedings.

**SUMMARY**

We have shown few cases of transverse coherent beam instabilities observed in the LHC during the 2012 physics run. The instabilities were mainly occurring at the end of the \( \beta \) squeeze and in the collision beam process. They have changed during the year as a consequence of changed parameters (\( Q’ \), octupoles currents and polarity and transverse damper gain). The origin of the instabilities is not understood yet however counter measures to have more stability are described for the different beam processes.