MD 754: Instability Threshold for Train with 25ns Spacing

L. R. Carver, D. Astapovych, N. Biancacci, G. Iadarola, T. Levens, E. Métral, B. Salvant, N. Wang (CERN, CH-1211 Geneva 23, Switzerland)

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Summary

Measurements made since the beginning of run II at 6.5 TeV have shown that there is a large discrepancy in the instability thresholds between single bunches and trains of 72 bunches with 25ns spacing, whereas the same result is expect for pure impedance-induced instabilities. One possible explanation is that the presence of electron cloud is affecting the beam stability. This MD will attempt to determine if electron cloud is the dominant mechanism affecting beam stability.

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1 Introduction

The single bunch instability threshold has been measured during run II (during commissioning and MD blocks) and has been shown to be 70A-100A [1] for $Q' = 7$. This is in good agreement with predictions from DELPHI [2].
During MD block 2, measurements of the instability threshold were made with a train of 72 bunches with 25ns bunch spacing [3]. The measured threshold was approximately 5 times higher than that observed for a single bunch. During these measurements, a synchronous phase shift along the train (indicative of the presence of electron cloud) was observed that was on the order of -0.8 degrees. The instability had an extremely fast rise time (1 second compared to 15s for single bunch) and the bunch profile showed a different type of head tail motion (1 node compared to 2 nodes for single bunch). It was clear that a different type of instability had occurred.

An overview of these measurements compared to single bunch measurements can be found in Fig. 1.

In order to determine if the primary mechanism for this increase in stability threshold is electron cloud, it is proposed to compare the instability thresholds of two different beams with different compositions. Ideally, a direct comparison would be made using a train of 72 bunches with 50ns spacing. However, due to the method of bunch splitting in the PS, it is not possible to create this beam without a 250ns gap in between the two trains of 36 bunches. This therefore motivates a comparison between the instability thresholds of two cases: (1) two trains of 36 bunches with 50ns bunch spacing, separated by 250ns and (2) two trains of 36 bunches with 25ns bunch spacing, separated by 250ns. The level of electron cloud for the 50ns train is anticipated to be much lower than for the train with 25ns bunch spacing. A discrepancy in the measured stability thresholds between these two cases will reveal some characteristics of this newly observed effect.

2 MD Procedure

Prior to MD block 3, case (1) was able to be performed. The results of these measurements will be described, before going on to describe the results of the MD.
2.1 Pre-MD: 2x36b with 50ns bunch spacing

The measurements were performed during fill 4345 on 10-09-15 between 13:30 and 16:30.

The bunch train was produced with a slightly blown up emittance (\(\sim 3\text{um}\)) in order to provide similar emittances for 25ns and 50ns variants and the required bunch pattern of 2x36b with 50ns spacing separated by a 250ns gap. The bunch train was produced with a slightly blown up emittance and the required bunch pattern of 2x36b with 50ns spacing. The following cycles were created for use in the PS Booster: 'PSB:LHC50_DB_A_PSB_Large_Emit:MD1' and 'PSB:LHC50_DB_B_PSB_Large_Emit:MD1'. These cycles were utilised together with a cycle for the PS named 'CPS:LHC50#36b_emittance:MD4'. The prepared LHC beam had a single bunch in the gated region (for cleaner tune measurements) and the 2x36b were placed between \(\sim\) bucket 1600 and 1750 (for 25ns bucket widths).

Figure 2: Overview of fill 4345, showing the octupole currents and the signal from the BBQ monitors. The octupole current was reduced in steps until an instability developed. The measured thresholds were consistent with single bunch measurements and DELPHI predictions.

An identical procedure to all previous instability threshold measurements is employed [1, 3, 4], whereby the beam is accelerated to 6.5TeV, the chromaticity is adjusted and the octupole current is incrementally reduced until an instability develops. An overview of the BBQ, beam intensity, and octupole currents for fill 4345 can be found in Fig. 2.

During the initial octupole reduction, the first 6 bunches in B2V became unstable at 94A. The headtail monitor acquired 11 consecutive turns which revealed two nodes in the headtail motion. This is shown in Fig. 3. During these instabilities, the first 2 bunches in the second batch became unstable in B2H. These instabilities showed similar headtail profiles to those seen in B2V.

Figure 3: Headtail profile for the first bunch of the first batch in B2V. Two nodes are clearly visible.

The octupole current in B1 was now returned to its maximum setting (550A) and the reduction was continued in B2. The current was reduced until it reached 37.6A, where the first bunch of the first batch became unstable in B1H. Fig. 4 shows the BSRT at the end of the fill, just prior to the dump, showing which bunches became unstable in each plane.

Throughout the fill, the synchronous phase shift was observed in order to see signs of electron cloud.
Figure 4: The bunch by bunch emittance from the BSRT in units of um. The unstable bunches in B2 are clearly visible, as well as a more subtle instability for the first bunch in B1H.

None was observed at any point in the fill, and the bunches became unstable individually at levels consistent with single bunches. The synchronous phase shift is nonetheless shown in Fig. 5

Figure 5: Synchronous phase shift along the train for B1 and B2, measured at the end of fill. A lack of synchronous phase shift indicates that there is little effect of the electron cloud on the beam.

As several bunches became unstable at once at thresholds that are consistent with measurements made for single bunches, it is difficult to differentiate between similar instabilities that occurred within each plane. Table 1 shows a summary of measured parameters for each plane that became unstable.

| Beam/Plane | Time | $4\sigma_t$[ns] | $\epsilon_H$[µm] | $\epsilon_V$[µm] | $N_b$[10$^{11}$] | $J_{oct}$[A] | $Q''H$ | $Q''V$ | $m$ | $|l|$ | M | $\tau$[s] |
|------------|------|----------------|-----------------|-----------------|----------------|-------------|--------|--------|-----|------|---|--------|
| B2V        | 17:32| 1.2            | 4.2             | 2.6             | 1.2            | 94          | 7      | 7      | 0   | 2    | 72 | 10.7   |
| B1H        | 17:32| 1.2            | 3.8             | 3.2             | 1.2            | 56          | 7      | 7      | 0   | 2    | 72 | -      |

Table 1: Summary of relevant parameters observed for the instabilities in fill 4345.
Another ramp was attempted with 2x36b with 25ns spacing that could immediately compare the stability threshold to this case. However, due to machine issues the fill had to be moved to MD block 3.

2.2 2x36b with 25ns bunch spacing

Having already performed measurements with 2x36b with 50ns spacing, it is decided to first measure the stability threshold for 2x36b with 25ns spacing, before repeating the measurement for 2x36b with 50ns spacing. This would then allow a direct comparison with very similar machine conditions. Initially, the 2x36b with 25ns spacing will be reported on. The first ramp was fill 4574 and was carried out between 01:00 and 04:00 on 05-11-15.

An overview of the final part of fill 4574 can be found in Fig. 6. It can be seen that an instability starts in B2V for octupole currents of 84.7A, and then again in B1H for currents of 75.3A. The headtail monitor also reveals two nodes in the headtail profile, which is similar to that seen in single bunch fills as well as with 2x36b with 50ns spacing. This is shown in Fig. 7.

![Figure 6: Overview of the instabilities seen during fill 4574. Shown is the currents in the octupoles alongside the signal from the BBQ monitor.](image)

![Figure 7: Headtail profile captured for the instability observed in B2V. Two nodes are clearly visible which is in accordance with the profile from previous measurements (see Fig. 3).](image)

| Beam/Plane | Time   | $\sigma_t$ [ns] | $\epsilon_H$ [$\mu$m] | $\epsilon_V$ [$\mu$m] | $N_b$ [$10^{11}$] | $J_{oct}$ [A] | $Q' H$ | $Q' V$ | $m$ | $|l|$ | M | $\tau$ [s] |
|------------|--------|----------------|------------------------|------------------------|------------------|---------------|---------|---------|-----|-------|---|----------|
| B2V        | 03:50  | 1.25           | 3.5                    | 2.8                    | 1.05             | 84.7          | 7.5     | 6.6     | 0   | 2     | 72 | 12       |
| B1H        | 03:53  | 1.25           | 3                      | 2.5                    | 1.05             | 75.3          | 8       | 7.0     | 0   | 2     | 72 | 42       |

Table 2: Summary of relevant parameters observed for the instabilities observed during fill 4574.

It was expected that the beam with 25ns would create more electron cloud than the beam with 50ns. This motivated a change of direction in the MD. Rather than repeat the measurement for 50ns (which would clearly also show single bunch instability thresholds), it was decided to repeat the measurement from MD2, and remeasure the instability threshold for 1x72b with 25ns spacing (the measurement that originally showed the large increase in the threshold). The results from this fill will now be discussed.
2.3 1x72b with 25ns bunch spacing

Fill 4577 occurred between and 09:10 and 10:27 on 05-11-2015. Due to time constraints, the 72 bunches were ramped together with the required 12 bunches for transfer line validation. However, there was sufficient gap between the two trains for there to be no coupling (from electron cloud) between them.

The chromaticity was again set to 7 in both planes (\(Q' = 15/15\) at flat top, was reduced by 8 units in both planes) and the octupole current was incrementally reduced until an instability developed, which is shown in Fig. 8. This threshold occurred at 66.6A when B2V became unstable. Due to time constraints, further instabilities could not be investigated and the beam was dumped.

Fig. 9 shows the headtail motion for the bunch that became unstable in B2V, and it can clearly be seen that it contains two nodes, meaning it is consistent with the other instabilities with trains of bunches. This therefore means it is a single bunch instability that is being observed. A summary of the observed characteristics of the instability can be found in table 3.


| Beam/Plane | Time   | \(4\sigma_t|\text{ns}\) | \(\epsilon_H|\text{um}\) | \(\epsilon_V|\text{um}\) | \(N_b|10^{11}\) | \(J_{oct}|A\) | \(Q'H\) | \(Q'V\) | \(m\) | \(|l|\) | \(M\) | \(\tau|s|\) |
|------------|--------|-----------------|-----------------|-----------------|----------------|----------------|---------|---------|------|------|------|-------|
| B2V        | 10:25  | 1.3             | 3               | 2.8             | 1.05           | 66             | 7       | 7       | 0    | 2    | 72   | 11.5  |
| B1H        | 10:27  | 1.3             | 2.8             | 2.5             | 1.05           | 50             | 7       | 7       | 0    | 2    | 72   | 29    |

Table 3: Summary of relevant parameters observed for the instabilities observed during fill 4577.
3 Discussion

There are now 4 sets of measurements that were acquired over the course of several months that need to be compared in the correct context. These are summarised in table 4. The measurements made for 2x36b can be found below in Fig. 10 and 11 and the measurements for 72b with 25ns bunch spacing can be found in Fig. 12.

<table>
<thead>
<tr>
<th>Date</th>
<th>Configuration</th>
<th>Q’/H/V</th>
<th>Norm. Threshold Current [A]</th>
<th>Sync. Phase Shift</th>
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<tbody>
<tr>
<td>28/08/15</td>
<td>1x72b_25ns</td>
<td>7</td>
<td>350-450</td>
<td>-0.8</td>
</tr>
<tr>
<td>10/09/15</td>
<td>2x36b_50ns</td>
<td>7</td>
<td>105-110</td>
<td>0</td>
</tr>
<tr>
<td>05/11/15</td>
<td>2x36b_25ns</td>
<td>7</td>
<td>75-100</td>
<td>-0.3</td>
</tr>
<tr>
<td>05/11/15</td>
<td>1x72b_25ns</td>
<td>7</td>
<td>60-85</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

Table 4: Summary of measurements made of the instability threshold of different train configurations.

Figure 10: Normalised instability threshold for both configurations of 2x36b alongside predictions from DELPHI for different damping times.

During the period between the 28/08/15 and 05/11/15, the LHC was running high intensity physics with 25ns beams. The intensity of the beams was steadily increased throughout, peaking at 2244 bunches per beam. This results in a large amount of scrubbing at 6.5TeV, something which is reflected in the behaviour of the heat load throughout the intensity ramp [5]. It seems consistent (with measurements and our current understanding of impedance and e-cloud effects in the LHC) to conclude that the scrubbing at flat top has reduced the level of e-cloud such that the interplay between impedance and electron-cloud is not strong enough to noticeably perturb the instability threshold. Future MD’s will aim to increase the intensity of the beam such that the level of e-cloud is higher, in order to further understand this mechanism.
Figure 11: A zoomed in plot of the normalised instability threshold for both configurations of 2x36b alongside predictions from DELPHI for different damping times. Plot colours are consistent with Fig. 10

Figure 12: Normalised instability threshold for trains of 72b with 25ns spacing alongside predictions from DELPHI for different damping times.

4 Conclusions

Due to scrubbing at flat top during the high intensity physics run, the level of e-cloud has been reduced such that we no longer see a factor of 5 in the instability threshold. This measurement is currently valid for 72 bunches per beam. As not much deconditioning is anticipated during the YETS, it is assumed these measurements will still be appropriate at the beginning of 2016. In the future, the instability threshold will be re-measured for several (up to 4) 72 bunch batches, in order to ascertain the e-cloud threshold required for this large increase in the stability threshold.
5 Acknowledgments

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References