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MD 346: Summary of single bunch instability threshold measurements

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Summary

The purpose of this MD is to measure the octupole current threshold to reach single-bunch stability in the LHC at flat top. Two bunches with different emittances are injected in the LHC in both B1 and B2 and the current in the Landau octupoles was progressively decreased until an instability developed. The measurements provide insight into the LHC impedance model by comparing them with the stabilising octupole current predicted from DELPHI.

Contents

1 Introduction

During the LHC operation in run I several instabilities occurred whose origin could not be identified from simulations [1, 2]. It is therefore important to assess the machine stability thresholds through measurements, both for operation during run II and to determine the available margins for future upgrades (in particular for HL-LHC). Models based on scaling with respect to the run I instabilities are available [3] and are the starting point for the new stability threshold measurements campaign during run II. Part of these measurements were able to be performed during LHC operation during the commissioning period, and the current status of the stability threshold measurements can be found in Fig. 1. It is clear from the figure that more points are required with chromaticities in the region of 7 and -4. The present MD aims to measure the instability threshold for these chromaticities in order to allow a systematic comparison for the octupole current thresholds between measurements and simulation results obtained with DELPHI [4]. Predictions from simulations can be also obtained using NHTVS [5], however the discrepancies between the two codes are still under investigation within the instability group: for the moment, DELPHI simulations will be adopted.

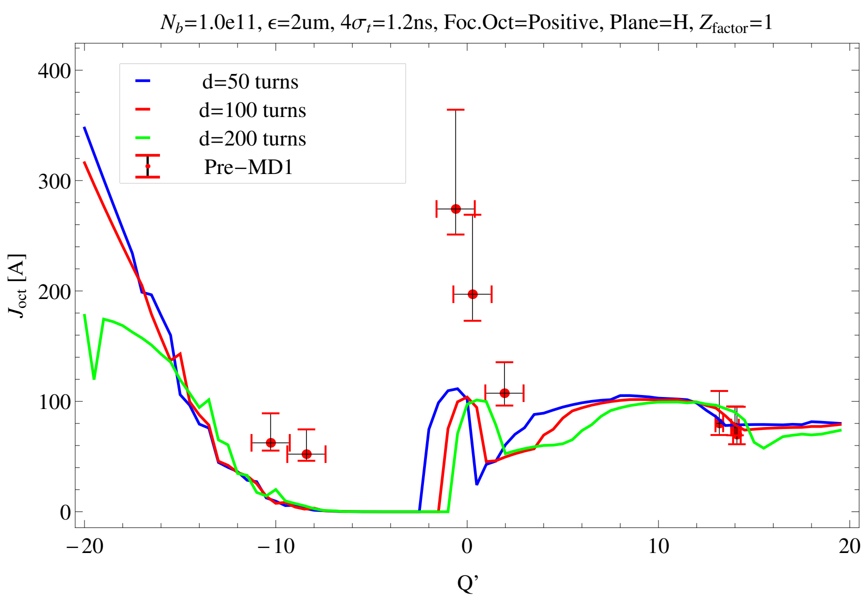

Figure 1: Summary of instability threshold measurements taken since the beginning of run II. Each point has been normalised with respect to the measured emittance and intensity and scaled for a nominal bunch ($\epsilon = 2$um and $N_b = 1.1 \times 10^{11}$ppb). DELPHI simulations refer to the present transverse impedance model (as it is, i.e. $Z_{\text{factor}} = 1$) for a perfect damper with damping times of 50, 100 and 200 turns. These points were taken from a variety of different settings, with some at flat top and others at end of squeeze, but each point is taken at 6.5 TeV. The full list of information regarding each instability can be found on the impedance website[1].

2 MD Procedure

The MD occurred on 24-07-2015 between 01:30 and 06:30 local time with fill number 4038.

Two single bunches are injected in B1 and B2, with intensities of 10^{11} ppb and emittances of $2\mu m$ and $3\mu m$. The BBQ system of the LHC allows for monitoring the bunches betatronic motion in the horizontal (H) and vertical (V) planes. The system can average along all the circulating bunches, (BBQ High Sensitivity or BBQ-HS), but it can also be used to isolate specific buckets in order to follow the motion of a limited amount of bunches (BBQ Gated or BBQ-G).
The bunch with $2\mu m$ emittance was placed inside the gated region, and the bunch with $3\mu m$ emittance was placed outside of the gate. Therefore the BBQ-HS is able to see both bunches, while the BBQ-G only the $2\mu m$ emittance one. The measurements were performed with the default damper operational

settings ($\simeq$100 turns), at collision tunes at flat top (non squeezed optics).

Fig. 2 provides an overview of the MD from data collected in TIMBER. The fill was divided into three sections, one for each useful instability that was observed (the momentum modulation for the chromaticity measurement triggered several instabilities and were therefore not useful for the study).

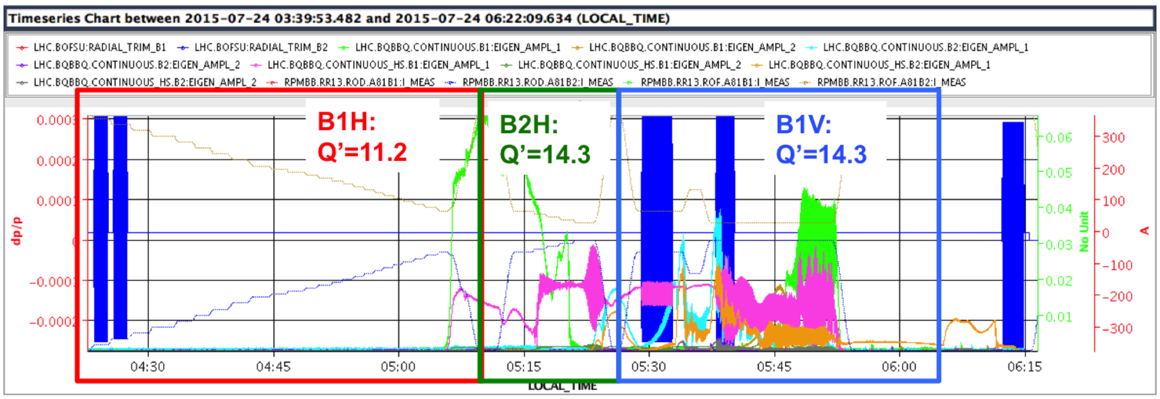

Figure 2: Overview of the MD showing octupole currents, BBQ activity and momentum modulation. The measurements have been divided into three sections to highlight each of the instabilities observed. The filled blue sections are the times when chromaticity measurements were made using the momentum modulation.

We measured the chromaticity with probes at injection and found that it was ~ 5 in both beams and planes. After the ramp, we attempted to re-measure the chromaticity, and determined from the online tool that it was approximately 10 in both beams and planes. Previous studies regarding octupolar feed down led us to believe that the chromaticity in H would become smaller with a decrease in octupole current [6]. However, post processing the tune and rf modulation data after the MD showed that the chromaticity was closer to 15 in both beams and planes.

In the first part of the MD (red block in Fig. 2), the octupole current was decreased in steps of $\simeq 20$ A in order to reduce the stabilizing tune spread. This caused the bunch with lower emittance to became unstable in B1H with a corresponding octupole current of 66 A. We increased the octupole current to allow the beam to stabilise. We were able to ascertain specifically which bunch became unstable by comparing the BBQ-HS with the BBQ-G.

We then continued to decrease the octupole current until it reached 28 A, at which point the bunch with the lowest emittance in B2H become unstable (this is shown by the green block in Fig. 2). The beams were then saved again by increasing the octupole current.

The unstable bunches showed persistent activity but was limited in amplitude (not growing). This allowed for accurate chromaticity measurements (RF trims in blue in Fig. 2) due to the strength of the tune peak in the spectrum. However, the momentum modulation excited several planes causing them to become unstable. We raised the octupole current by approximately 50A to allow them to stabilise once more.

[1] http://impedance.web.cern.ch/impedance/

During the final part of the MD, we decreased the octupole current again until B1V became unstable. This occured at 28 A (blue block in Fig. 2).

The chromaticities were measured as $Q'_H = 11.2$ and $Q'_V = 13$ in B1 and $Q'_H = 14$ in B2. Unfortunately the data quality does not allow a good measurement of the Q'_V in B2.

The relevant parameters concerning the instability observations are displayed in Tab. 1 and a detailed set of figures showing the bunch behaviour in time and frequency domain can be found in appendix. A detailed analysis allows the azimuthal mode number for the instability, m, to be defined. It can be seen in Fig. 5, for example, that $m = 0$ for the first instability in B1H. The rise time τ is deduced from the coherent exponential growth during the instability. The radial mode number was triggered only during the first two instabilities and it indicated the presence of a mode $l = |2|$ that was the primary unstable mode. This is shown in Fig. 3 for the first instability observed. The figure shows two different snapshots from the headtail monitor, the first is during the initial growth period of the instability, the second is after it has been oscillating for approximately two minutes.

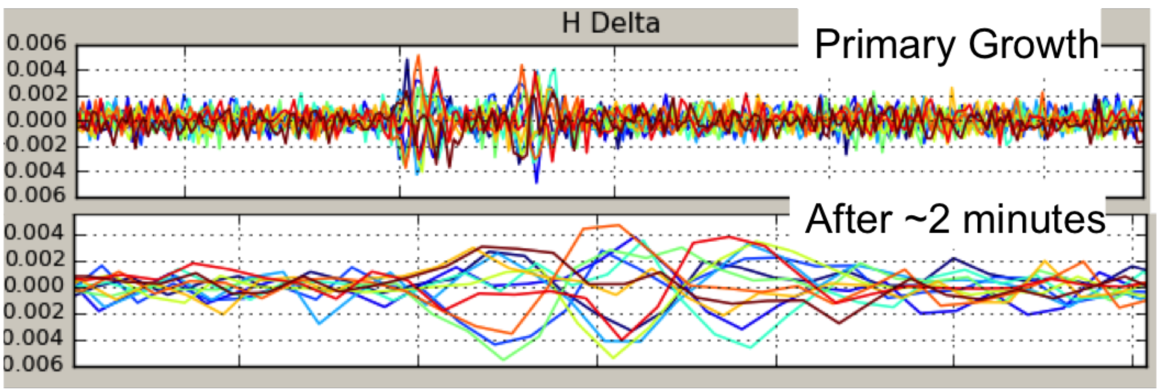

Figure 3: Head tail monitor showing two different snapshots of inter bunch motion at two different times during the first instability of B1H. The top plot shows a wide scan of a very weak signal taken over the first bunch, where each horizontal grid spacing is 50 ns. The lower plot shows a zoomed plot of the same bunch approximately 2 minutes later, where each horizontal grid spacing is now 5 ns.

Beam/Plane	Time	$4\sigma_t$[ns]	ϵ_H[μm]	ϵ_V[μm]	N_b[10^{11}]	J_{oct}[A]	$Q'H$	$Q'V$	m	$\|l\|$	M	τ[s]
B1H	05:04	1.2	2.4	1.95	1.14	66	11.2	13	0	2	1	10
B2H	05:23	1.2	2.0	1.6	1.16	28.2	14.4	-	0	2	1	17
B1V	05:41	1.2	$\gg 2.4$	1.95	1.0	28.2	11.2	13	0	-	1	65

Table 1: Summary of relevant parameters observed for each instability.

Fig. 4 shows the current status of single bunch measurements at flat top, with the results measured during the MD shown in blue. Also shown is DELPHI simulation results for different damping times. Each measured point has been normalised with respect to the measured emittance and intensity and scaled to the parameters used in the simulation. One of the largest uncertainties on the measurements taken so far is with the damping time of the ADT, however it can be seen that for positive chromaticities, this should not have a large effect on the octupole threshold. It can therefore be seen that DELPHI shows reasonable agreement for positive chromaticities, especially around values of 10-15.

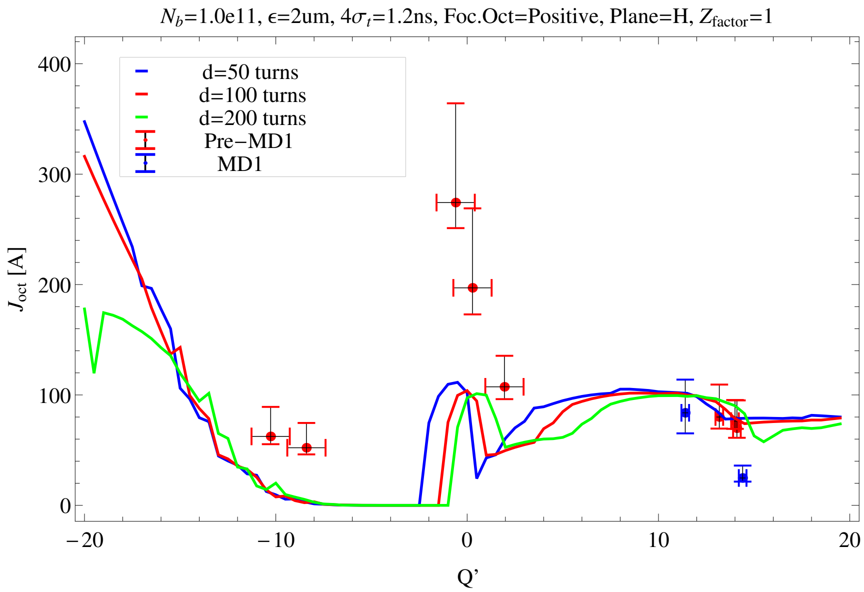

Figure 4: The current status of single bunch instability measurements overlaid with the results from DELPHI simulations. The DELPHI simulation was performed with a single bunch of $2\mu m$ emittance, 1×10^{11} intensity, 1.2 ns bunch length and is plotted for a damping time of 50, 100 and 200 turns (blue, red and green respectively). Each measured point has been normalised to the same bunch parameters used for the simulation.

3 Conclusions

Due to the error in the chromaticity measurement at flat top, we were unable to probe the instability regions of interest. The measurements that were made were found in regions that previous measurements had already searched. Additional ramps were attempted, but they were dumped due to problems with the RCS system.

The measurements that were made during this MD showed a good level of reproducibility for single bunch instability thresholds, but further beam time will be required in order to gain a clearer picture of the instability threshold closer to operational parameters.

4 Acknowledgments

We would like to acknowledge the LHC and injectors operators for their help during the machine setup.

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5 Appendix

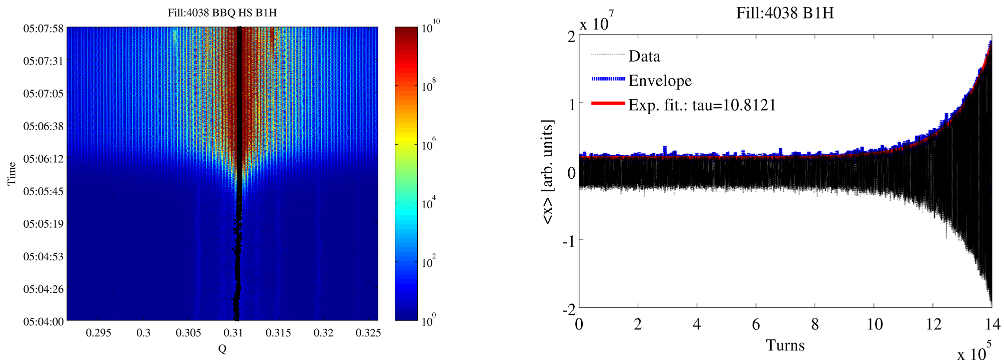

Figure 5: Left: spectrogram of the B1H instability showing an arising azimuthal mode $m = 0$. Black dots refers to the highest amplitude line calculated with the iterative Fourier Transform code NAFF. Right: exponential fit to the amplitude growth.

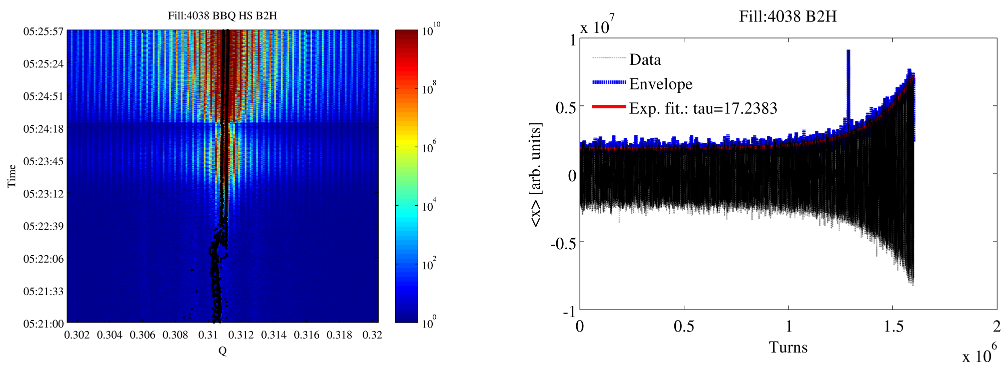

Figure 6: Left: spectrogram of the B2H instability showing an arising azimuthal mode $m = 0$. Black dots refers to the highest amplitude line calculated with the iterative Fourier Transform code NAFF. Right: exponential fit to the amplitude growth.

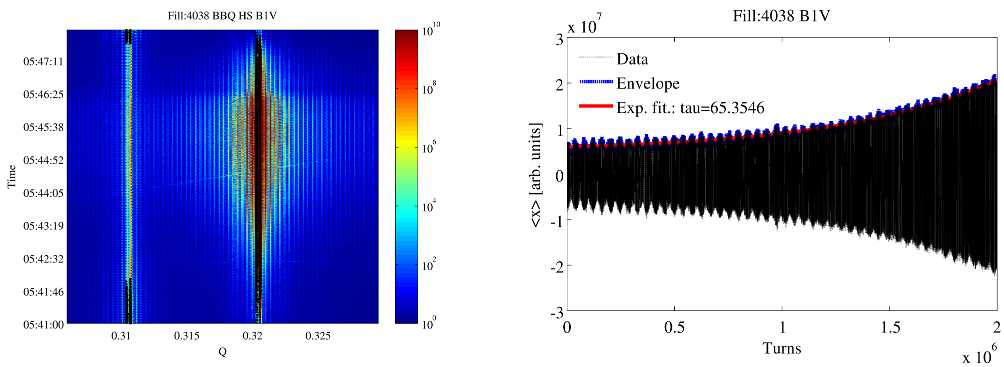

Figure 7: Left: spectrogram of the B1V instability showing an arising azimuthal mode $m = 0$. Black dots refers to the highest amplitude line calculated with the iterative Fourier Transform code NAFF. Right: exponential fit to the amplitude growth.