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LHC MD 652: Coupled-Bunch Instability with Smaller Emittance (all HOMs)

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Abstract

The aim of the MD was to measure the coupled-bunch stability from all HOM impedances, with a reduced longitudinal emittance in order to explore the HL-LHC conditions. The acceleration ramp was performed with the nominal beams of 2016, but a reduced target bunch length and RF voltage. With this reduced emittance, the beam remained close but above the single-bunch stability threshold. No coupled-bunch oscillations were observed, so we can conclude that the stability threshold for coupled-bunch instability is not lower than the single-bunch threshold. An interesting observation in the MD was the long-lasting injection oscillations, whose traces can still be seen at arrival to flat top; in agreement with observations in earlier MDs.

The measurements took place between 28th October 20:00 and 29th October 05:10.

Contents

1 Introduction

The single-bunch stability threshold of the LHC has been determined with good accuracy in past MDs [1]. Whether or how much the coupled-bunch stability threshold is lower than the single-bunch threshold was the subject of the MD presented here. To explore the HL-LHC stability requirements, as the bunch intensity could not be increased, we scaled instead the longitudinal emittance to an appropriate value.

2 MD timeline and beam conditions

The MD started with five and a half hour delay due to an access for the QPS and an ATLAS intervention. At 01:34, beam injection was finally started. The first part of the MD was dedicated to a test of coupled-bunch instabilities due to the cavity fundamental impedance (MD376) discussed in [2]. At 02:35, injection for the actual MD has started. After acquisition of sufficient data, studies for MD376 continued at flat top from 04:36 till 05:10, which marked the end of the MD.

We injected 2220 bunches (with BCMS production scheme) in both beams with nominal intensity, varying between (1.0-1.2)$\times 10^{11}$ ppb along the batch, and nominal bunch length at injection, 0.9-1.0 ns right after capture. The decreased beam emittance at arrival to flat top has been obtained by both lowering the RF voltage and the bunch length target for the controlled emittance blow-up during the ramp. The RF voltage was increased linearly from 6 MV to 7.5 MV in the ramp, instead of from 6 MV to 10 MV as was done for proton operation in 2016. The target bunch length was 1.25 ns in the first two-thirds of the ramp, after which it was set to 1.1 ns and 1.05 ns in B1 and B2, respectively.

Peak-detected Schottky spectra and the bunch-by-bunch stable phase has been acquired during the MD to identify possible oscillations.

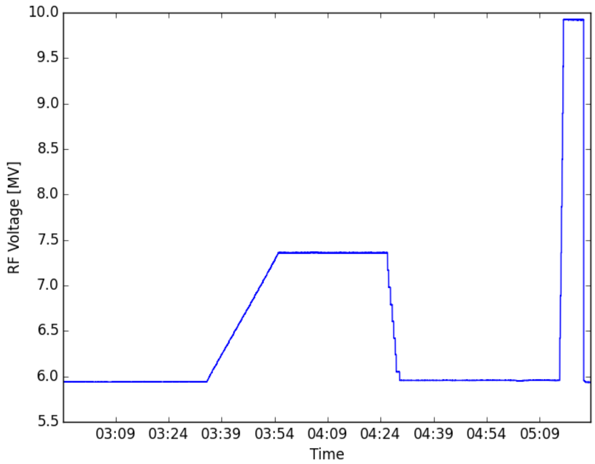
3 MD results

Both beams arrived with a similar mean bunch length to flat top, B1 with 1.06 ns and B2 with 1.04 ns. Some undamped beam phase oscillations were detected, but their amplitude did not grow. No obvious coupled-bunch mode could be detected neither with these beam parameters.

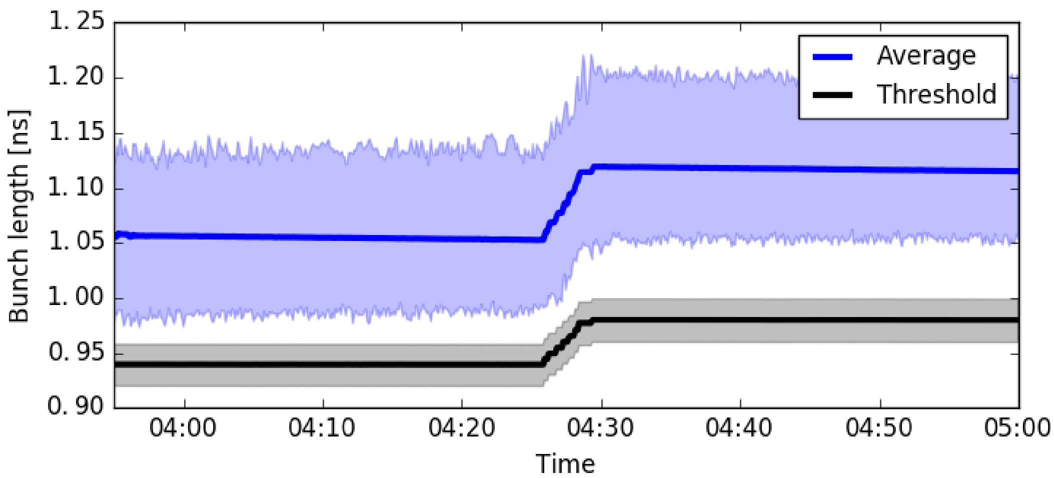
Next, we investigated the effect of decreased and increased voltage on B1 and B2, respectively. In both directions, the voltage change was done in steps of 0.2 MV to be as adiabatic as possible. The RF voltage and bunch length evolution of B1 are shown in Fig. 1; the voltage has been decreased from 7.5 MV to 6 MV at flat top. For B2, the voltage was first increased from 7.5 MV to 12 MV see Fig. 2; the later reduction to 10 MV was done for MD376. The shortest bunches in B2 remained just at the single-bunch stability threshold determined in [1], while B1 remained about 30-50 ps above the threshold bunch length.

Both the increase and the decrease of the RF voltage provoked some bunch phase oscillations. The amplitude of dipole oscillations is shown in Fig. 3; some bunches have undamped oscillations, but the oscillation amplitude of most bunches decreases over time. The preliminary mode analysis of these oscillations indicates rather a single-bunch effect. However, a more careful analysis of the oscillation modes still needs to be carried out before drawing a final conclusion.

Looking at the bunch-by-bunch stable phase, the amplitude of oscillations shows an interesting pattern at arrival to flat top along the ring, see Fig.4. There is a clear correlation of the amplitude of oscillation with the longitudinal position in the ring. However, this is not a result of some coupled-bunch motion, since a more detailed analysis shows that the oscillation amplitude is proportional to the time a given batch spent at flat bottom, see Fig. 5. Thus the oscillations observed at arrival to flat top are acually undamped injection oscillations. If all batches spend a long enough time at flat bottom, there are no oscillations at arrival to flat top neither. With what mechanism the injection oscillations 'survive' the noise injection of the controlled longitudinal emittance blow-up during the ramp still needs to be studied. A possible explanation is that the controlled emittance blow-up using band-limited noise creates resonant islands and oscillations at certain frequencies that do not necessarily influence the injection rigid-bunch oscillations.

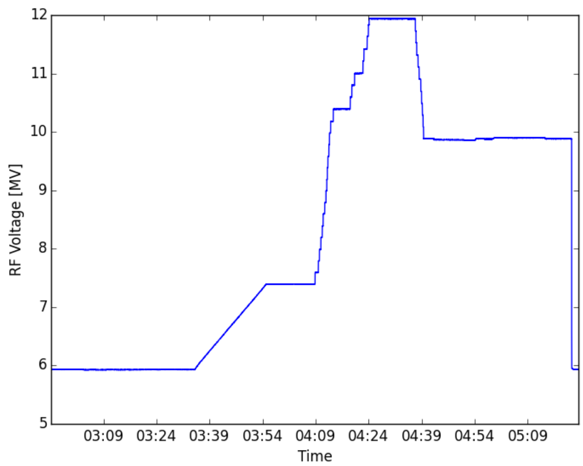


(a) RF voltage programme during the MD. The voltage was decreased from 7.5 MV to 6 MV at flat top.

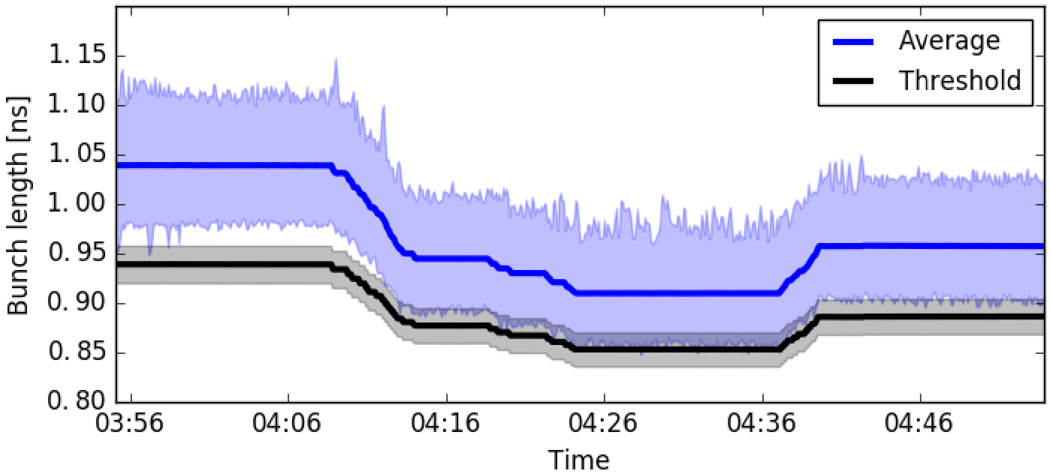


(b) Mean bunch length and bunch length spread (blue) compared to the single-bunch stability threshold (black), at flat top. The increase in bunch length is due to the voltage decrease from 7.5 MV to 6 MV.

Fig. 1: B1 parameters during the MD. The acceleration ramp was performed between 03:34 and 03:54.

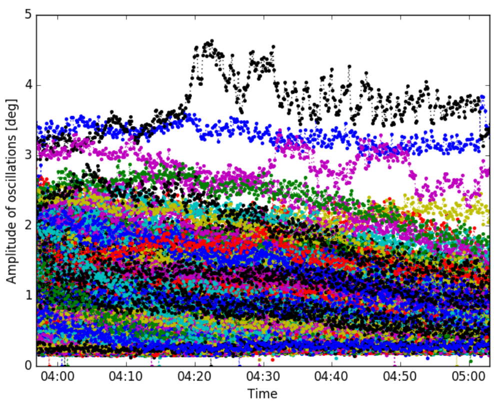


(a) RF voltage programme during the MD. The voltage was increased from 7.5 MV to 12 MV at flat top.

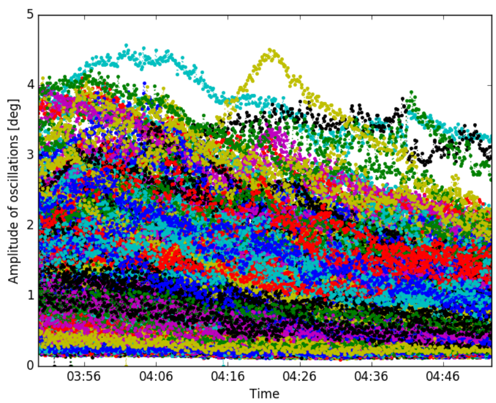


(b) Mean bunch length and bunch length spread (blue) compared to the single-bunch stability threshold (black), at flat top. The decrease in bunch length is due to the voltage increase from 7.5 MV to 12 MV.

Fig. 2: B2 parameters during the MD. The acceleration ramp was performed between 03:34 and 03:54.

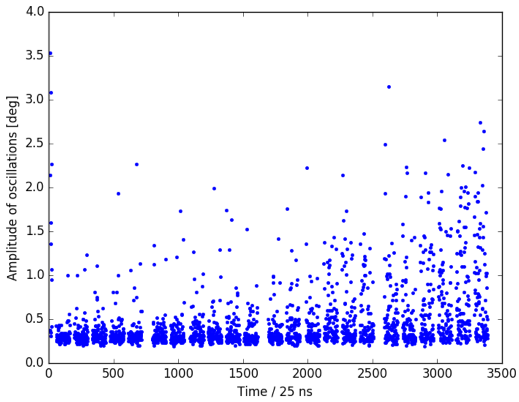


(a) B1.

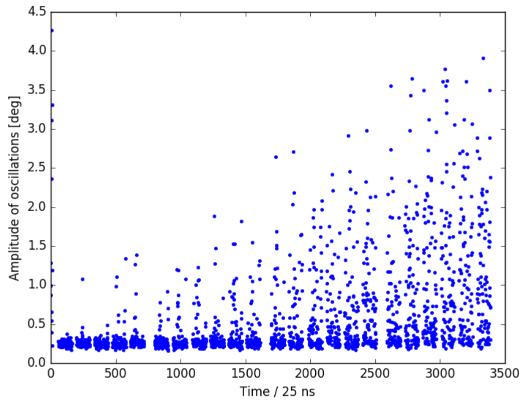


(b) B2.

Fig. 3: Amplitude of dipole oscillations, bunch by bunch, as a function of time.

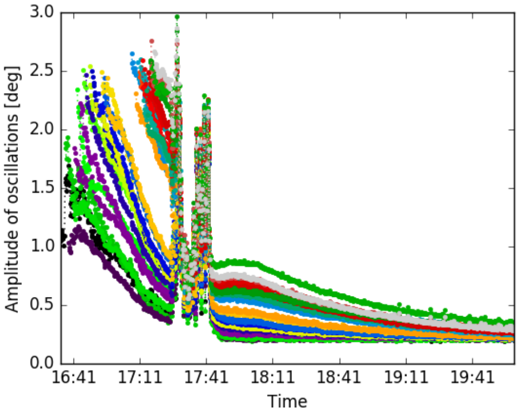


(a) B1.

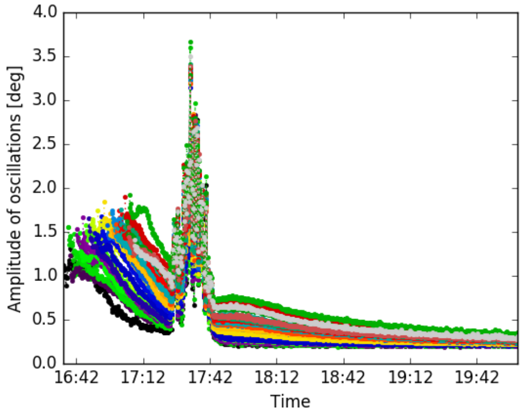


(b) B2.

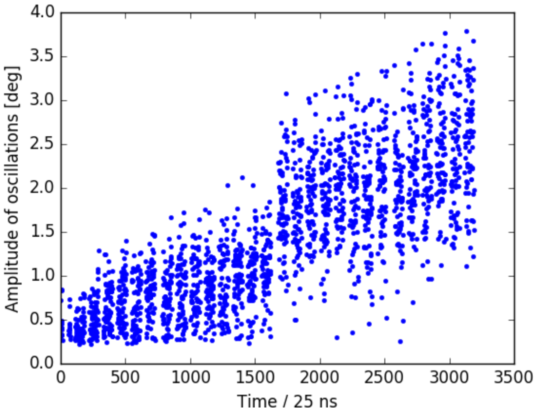
Fig. 4: Amplitude of dipole oscillations at arrival to flat top, bunch by bunch, as a function of longitudinal position. The RF voltage was 7.5 MV.



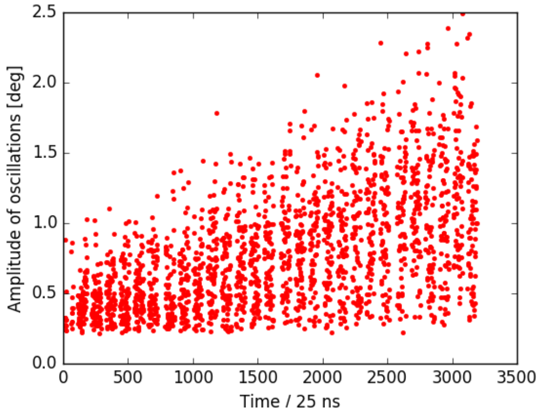
(a) B1: evolution of batch-by-batch bunch phase during the fill; ramp from 17:23 to 17:43.



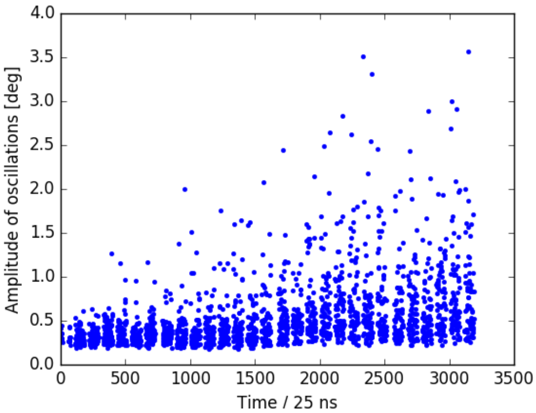
(b) B2: evolution of batch-by-batch bunch phase during the fill; ramp from 17:23 to 17:43.



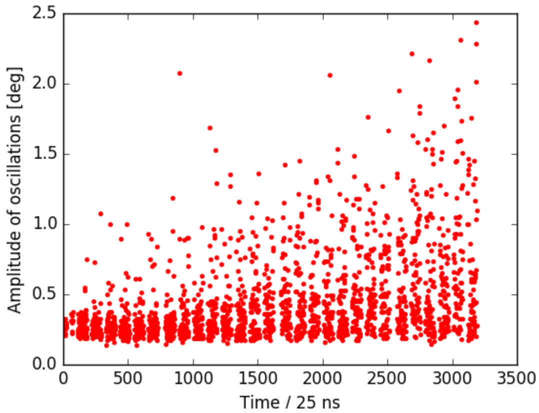
(c) B1: bunch-by-bunch oscillations along the ring, at flat bottom.



(d) B2: bunch-by-bunch oscillations along the ring, at flat bottom.



(e) B1: bunch-by-bunch oscillations along the ring, at arrival to flat top.



(f) B2: bunch-by-bunch oscillations along the ring, at arrival to flat top.

Fig. 5: Amplitude of dipole oscillations in physics fill no. 5029. The shorter the time spent at flat bottom, the larger the amplitude of oscillations at arrival to flat top. Beam 1 (left) and Beam 2 (right).

4 Conclusions

In the MD, the coupled-bunch stability for the full LHC has been studied with beam parameters in the vicinity of the single-bunch stability threshold in the HL-LHC regime. The latter has been obtained by decreasing the RF voltage and the target bunch length for the controlled longitudinal emittance blow-up in the ramp, resulting in small-emittance beams at flat top. No clear coupled-bunch oscillations were observed, implying that the LHC longtidunal coupled-bunch stability threshold is not lower than the single-bunch one, at least for the present BCMS-type beam configuration.

Observations of correlated beam phase oscillation amplitudes at flat bottom and flat top suggest that injection oscillations are preserved throughout the ramp. Their amplitude depends on the time spent at flat bottom; full damping requires about an hour at injection.

Acknowledgements

We wish to thank the operators of the LHC and injectors for their kind assistance during the measurements.

5 References

[1] J. Esteban Müller et al., *LHC Longitudinal Single-Bunch Stability Threshold*, CERN-ACC-NOTE-2016-0001, (2016).

[2] T. Mastoridis et al., *Coupled-Bunch Instabilities due to Fundamental Cavity Impedance*, CERN-ACC-NOTE-2017-0009, (2017).