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MD 3290: Instability threshold measurements in the presence of a controlled external excitation

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Abstract

During the MD 2722 an unexpected instability was observed at flat top energy during BTF measurements. Simulation studies have shown an decrease of the instability thresholds according to the impedance level when in the presence of a small external excitation amplitude. In this note we summarise the results of the MD 3290 devoted to measure the instability thresholds in the presence of a controlled external excitation introduced by the use of the BTF system. The MD procedure is described and the presented results will be used as a reference in order to avoid instabilities during future BTF measurements at flat top energy.

Keywords: Accelerator physics, beam-beam effects, beam instabilities, Beam Transfer Function, stability diagram

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1 Motivation

At the LHC, the BTF system is used during dedicated MDs in order to measure the Landau damping of the beams in different configurations [1–3]. During the previous MD (2722) in 2017 [4], an unexpected instability was observed at flat top energy during BTF measurements with a small excitation amplitude already used in the past without causing instabilities. Simulations demonstrated that stability thresholds change in the presence of noise [5] or small external excitation amplitude [6]. The observed instability was reproduced and a correlation with the increase of the impedance of about 30% w.r.t. 2016, was found. Figure 1 shows the simulated stability thresholds as a function of the chromaticity in the presence of an external BTF excitation including the impedance model of 2017. The black dashed line represents the expectations without external excitation. The two cases behave similarly for small chromaticity value ($Q' \approx 2$) but for higher chromaticity values the stability threshold increases by up to 50% for a chromaticity $Q' \approx 10$ units.

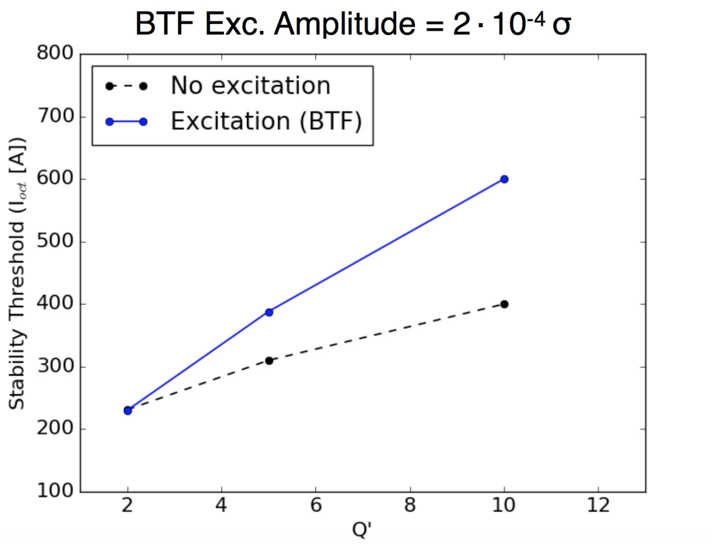


Fig. 1: Simulated (COMBI) stability thresholds in octupole current as a function of the chromaticity in the presence of an external BTF excitation of $2 \times 10^{-4}\sigma$. The black dashed line is the expectation without external excitation.

This MD was dedicated to the study of the impact of an external excitation on the stability of the beams for various impedance levels and it be considered as a reference for next BTF MDs, defining in particular, the BTF settings in order to avoid instabilities during measurements.

2 MD procedure and preliminary results

The experiment was carried out on June 17$^{\text{th}}$, 2018. The first part of the MD was carried out at injection energy and it was dedicated to the setup of the gated BTF system, which allows to excite and acquire the BTF signal bunch by bunch, and was successfully used for the first time during this MD. During the second part of the MD we injected 40 bunches per beam of various intensities: 0.6×10^{11}, 0.8×10^{11}, 1.0×10^{11} and 1.2×10^{11} p/bunch (with ≈ 10 bunches per intensity), as shown in Fig. 2.

At flat top energy with 450 A octupoles the Beam 2 got unstable therefore we increased the octupole current to 510 A but we could not switch off the transverse feedback (ADT) on Beam 2 that was unstable also for low intensities bunches. So we focused the measurements only on Beam 1 for which we performed the excitation amplitude scan for both planes. During the scan we switched off the ADT on the selected bunch one plane at a time. We kept the ADT switched on for the other bunches in the beam. The measurements were performed for a chromaticity $Q' \approx 15$ units and for various octupole currents (510 A, 450 A and 375 A). On the selected bunch we scanned the BTF amplitude till signs of instability were observed on the measured bunch (i.e. emittance blow-up). The results of the measurements are summarised in Fig. 3 where the maximum BTF excitation allowed before triggering instabilities is

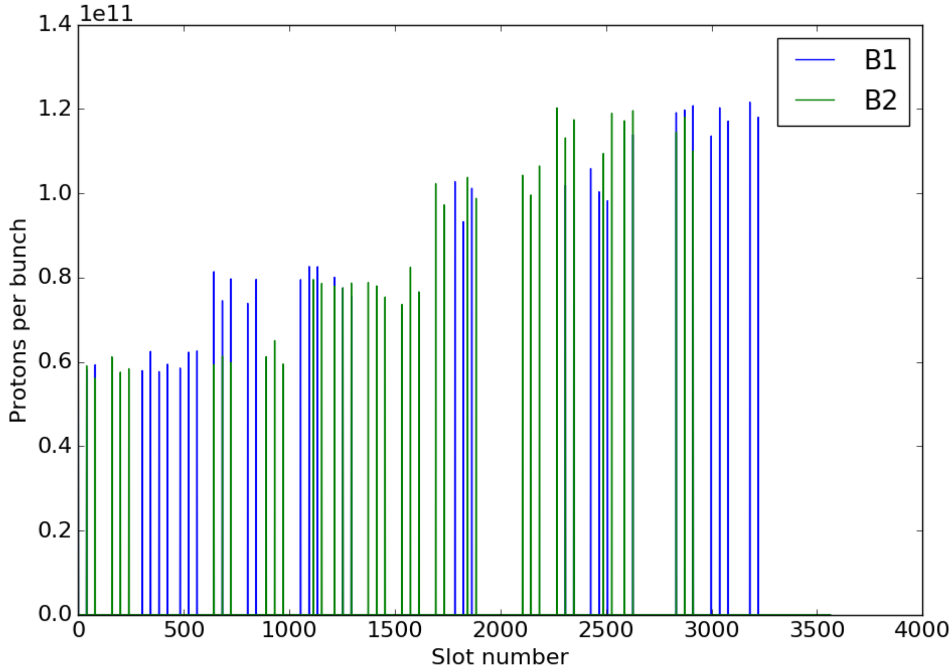
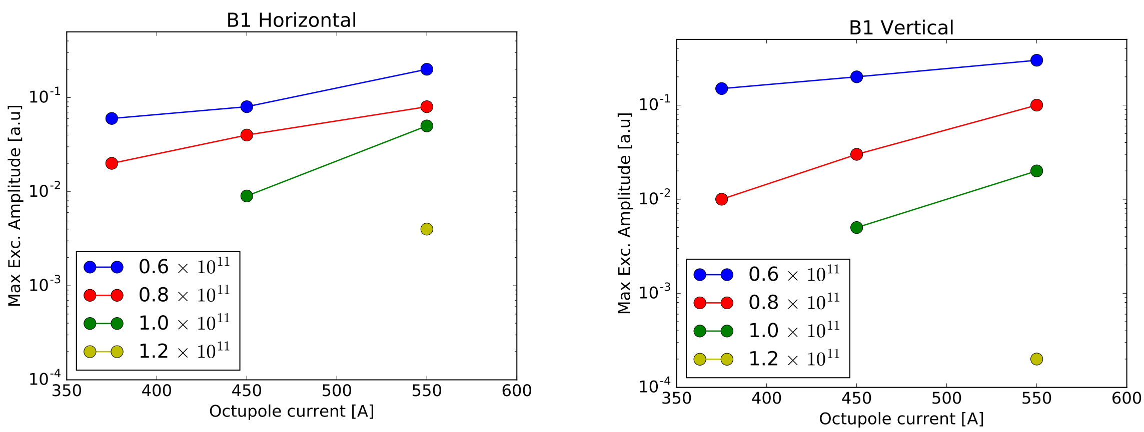


Fig. 2: Bunch by bunch intensity for Beam 1 and Beam 2.

plotted as a function of the octupole current and for various bunch intensities. As expected, there is an evident dependency on the bunch intensity: the higher the intensity the smaller the excitation amplitude allowed without triggering instabilities. This confirms the correlation with the impedance level in the machine. The maximum excitation amplitudes are observed to be lower in the vertical plane, for which the emittance was $\varepsilon_{norm} \approx 1.2\,\mu$m, and higher in the horizontal plane, for which the emittance was $\varepsilon_{norm} \approx 1.8\,\mu$m. This is in contradiction with expectations since for Landau damping is the emittance in the opposite plane that mostly contributes in the amplitude detuning for stabilization in the presence of positive octupole polarity. However, the difference between the two planes could also depend on the calibration of the excitation that might be slightly different it the two planes.

It was also observed that the maximum excitation amplitude increases in a monotonic way as a function of the Landau octupole current. The higher intensities (1.2×10^{11} p/bunch) bunches were



(a) B1 horizontal plane.

(b) B1 vertical plane.

Fig. 3: Maximum BTF excitation allowed before triggering instabilities as a function of the octupole current for various bunch intensities.

unstable without excitation when the transverse feedback was switched-off therefore no thresholds could be measured for octupoles below 510 A. COMBI [7] simulations confirmed the observed trend. Figure 4 shows the simulated maximum excitation amplitudes (before the bunch becomes unstable) as a function of the octupole current for various bunch intensities (0.6×10^{11}, 0.8×10^{11} p/bunch). The monotonic trend as a function of the octupole current is reproduced and for the highest bunch intensity used (the blue line) the stability thresholds are lower compared to the lowest bunch intensity (the red line), as observed during the measurements.

For Beam 2 the bunches at 0.6×10^{11} p/bunch with a normalized emittance of $\varepsilon_{norm} \approx 1.7\,\mu$m were unstable without excitation as soon as the feedback was turned off. This behavior needs to be further analysed and understood.

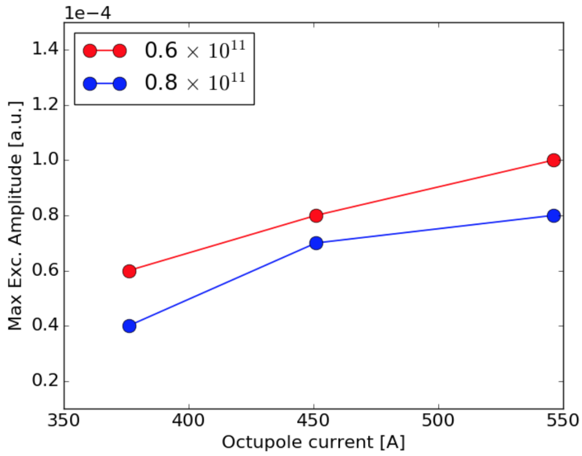


Fig. 4: Simulated maximum excitation amplitudes (before the bunch becomes unstable) as a function of the octupole current for 0.6×10^{11}, 0.8×10^{11} p/bunch intensities.

3 Summary

The first part of the MD at injection energy was dedicated to the setup of the gated BTF system. The second part of the MD was carried out at flat top energy. We measured the impact of different impedance levels on beam stability (through different bunch intensities) when in the presence of a controlled external excitation introduced by the BTF. The measurements showed that the maximum excitation amplitude before triggering a beam instability decreases as a function of bunch intensity while it increases as a function of the octupole current. COMBI simulations reproduce the same trend. From the observation we can deduce that a stronger impedance yields the beams to be much more sensitive to any external source of noise/excitation. This could explain why no instabilities triggered by BTFs were observed in 2016 at flat top energy as the impedance was smaller by 30% than in 2017. The performed excitation amplitude will be used to safely excite the beams by using the BTF at flat top for the next BTF MDs. (Detailed analysis is ongoing to understand the observed instabilities on Beam 2 without BTF excitation).

4 Acknowledgements

We would like to thank the OP crews on shift and BI team.

5 References

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