Noise studies with Crab Cavities in the SPS for the HL-LHC project

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy

by

Natalia Triantafyllou

Day Month Year

Abstract

Acknowledgments

List of Figures

List of Tables

List of Symbols

E	Energy
f_{rev}	Revolution frequency
V_{RF}	RF voltage
f_{RF}	RF frequency
V_{CC}	CC voltage
f_{CC}	CC frequency

Contents

Chapter 1

Introduction

This is the introduction of my PhD thesis.

Testing for footers and headers Testing citation [1]. wefefklje

Test list of symbols with E .

Chapter 2

Basics of accelerator beam dynamics

Chapter 3

Theory of Crab Cavity noise induced emittance growth

Chapter 4

First experimental campaign in the SPS

In 2018, two prototype Crab Cavities (CCs) were installed in the SPS to be tested for the first time with proton beams. One of the operational issues that needed to be addressed concerned the expected emittance growth due to noise in their RF control system. A theoretical model that describes this emittance growth had already been developed and validated by tracking simulations [1]. Based on those studies a dedicated experiment was performed to benchmark the models with experimental data and to confirm the analytical predictions. In particular, the idea was to inject various noise levels in the CC RF system and record the emittance evolution. In this chapter, the experimental procedure, the measurement methods and results are presented and discussed.

The chapter is stractured as follows: Section 4.1 describes the operational setup for the SPS CC tests and discusses the main diagnostic deployed for the derivation of the CC voltage.

blah blah ... describe sections and subsections after they are completed.

4.1 Crab Cavities in the SPS

For the SPS tests two prototype CCs of the Double Quorter Wave (DQW) type were fabricated by CERN and were assembled into the same cryomodule [2]. The cryomodule was installed in the SPS-LSS6 zone and was placed on a mobile transfer table [3]. The table moved with high precision and without breaking the vaccum the cryomodule in the beam line for the CC tests and out of it for the usual SPS operation.

Thw two CCs installed in SPS are intended for the LHC and thus they operate at its acceleration frequency at 400 MHz. However, in the SPS the main RF system operates at 200 MHz. In order to make sure that the beam will experience the same effect from the CC each turn the SPS main RF has to be re-phased such as it becomes synchronous with the CC signal. The CC tests in 2018 were conducted at the injection energy of 26 GeV and at 270 GeV. In the first case the synchronisation took place shortly after the injection. In the second case the CCs were switched off during the energy ramp to 270 GeV. At the end of the ramp the cavities were switched on and the synchronisation took place shortly after.

4.1.1 Measurement of the Crab Cavity voltage

As a part of the first experimental campaign a comparison of the available diagnostic devices for measuring the CC voltage was performed [4]. It was shown that the headtail monitor [Ref] should be used as the primary diagnostic device

What is it? Explain breifly and find ref Where is the measurement based? Closed orbit.

What is needed –> unsynchronised

The effect of the CC on the beam was measured

Voltage measurement with HT monitor. blah balah. why was it chosen over the other instruments.

4.2 Experimental procedure

4.2.1 Machine and beam configuration

4.2.2 Measurement methods

What do we measure and how? emittance (show plot ws) bunch length ABWLM –> we take the measurement directly from the resposnible tema –> show also from the instrument that we saw the unstable bunches.

4.3 Experimental resutls

4.3.1 Overview

- bunches 2, 3 and 4 unstable

4.3.2 Comparison with the theory

This chapter is adapted from the the studies published in Ref. [5]

4.4 Experimental Setup

Several experimental studies have been performed (2010-2017) to identify the optimal conditions for the emittance growth studies with CCs in the SPS [6, 7]. Based on these preparatory studies, the measurements in the SPS were performed with four low intensity ($\sim 3 \cdot 10^{10}$ ppb) bunches at 270 GeV. To minimise the emittance growth from other sources [7] the first order chromaticity, Q', of the machine was corrected to small positive values ($\sim$ 1-2) in both the horizontal and the vertical planes. During the measurements the Landau octupoles were switched off. It should be note, though, that a residual non-linearity was present in the machine mainly due to multipole components in the dipole magnets [8, 9]. Only one CC was used, providing a vertical kick to the beam. The transverse feedback system was switched off. Even though the emittance growth is a single bunch effect four bunches were used to reduce the statistical uncertainty of the measurements. The distance between the bunhces was 524 ns. An overview of the relevant SPS parameters during the experiment is given in Table 4.1.

Table 4.1: SPS parameters during the 2018 MD studies.

Parameters	**Values**
E_b	270 GeV
f_{rev}	43.375 kHz
ν_x, ν_y	26.13, 26.18
ν_s	0.0051
V_{RF}, f_{RF}	5 MV, 200 MHz
$\beta_{x,\mathrm{CC}}$, $\beta_{y,\mathrm{CC}}$	30.31 m, 73.82 m
V_{CC}, f_{CC}	1 MV, 400 MHz

4.4.1 Injected RF noise

In order to characterize the CC noise induced emittance growth, controlled noise was injected into their LLRF system and the evolution of the bunch was recorded for about 20-40 minutes. The injected noise was a mixture of amplitude and phase noise up to 10 KHz, overlapping and primarily exciting the fisrt betatron sideband at $\sim$ 8 kHz. The phase noise was always dominant.

Chapter 5

Investigation of the discrepancy

Chapter 6

Simple model of describing the decoherence suppression from impedance

Chapter 7

Application and impact for HL-LHC

Chapter 8

Conclusion

Appendix A

Appendix Title

Bibliography

[1] P. Baudrenghien and T. Mastoridis. "Transverse emittance growth due to rf noise in the high-luminosity LHC crab cavities". In: *Phys. Rev. ST Accel. Beams* 18 (10 Oct. 2015), p. 101001. DOI: 10.1103/PhysRevSTAB.18.101001. URL: https://link.aps.org/doi/10.1103/PhysRevSTAB.18.101001.

[2] C. Zanoni et al. "The crab cavities cryomodule for SPS test". In: 874 (July 2017), p. 012092. DOI: 10.1088/1742-6596/874/1/012092. URL: https://doi.org/10.1088/1742-6596/874/1/012092.

[3] Marco Garlaschè et al. "Assembly of the DQW Crab Cavity Cryomodule for SPS Test". In: (2018), WEPMF078. 4 p. DOI: 10.18429/JACoW-IPAC2018-WEPMF078. URL: https://cds.cern.ch/record/2648553.

[4] Lee Carver et al. "First machine development results with HL-LHC crab cavities in the SPS. First machine developments result with HL-LHC crab cavities in the SPS". In: (2019), MOPGW094. 4 p. DOI: 10.18429/JACoW-IPAC2019-MOPGW094. URL: https://cds.cern.ch/record/2696108.

[5] Natalia Triantafylou. "INVESTIGATION OF DAMPING EFFECTS OF THE CRAB CAVITY NOISE INDUCED EMITTANCE GROWTH". In: (2021), TBA. DOI: TBA. URL: TBA.

[6] R Calaga et al. "Proton-beam emittance growth in SPS coasts". In: *Conf. Proc.* C1205201 (May 2012), THPPP007. 3 p. URL: https://cds.cern.ch/record/1451286.

[7] Fanouria Antoniou et al. "Emittance Growth in Coast in the SPS at CERN". In: *J. Phys.: Conf. Ser.* 1067 (2018), MOPMF061. 7 p. DOI: 10.18429/JACoW-IPAC2018-MOPMF061. URL: https://cds.cern.ch/record/2649815.

[8] Michele Carlà et al. "Studies of a New Optics With Intermediate Transition Energy as Alternative for High Intensity LHC Beams in the CERN SPS". In: (2018), TUPAF022. 4 p. DOI: 10.18429/JACoW-IPAC2018-TUPAF022. URL: https://cds.cern.ch/record/2664976.

[9] Androula Alekou et al. "SPS Long Term Stability Studies in the Presence of Crab Cavities and High Order Multipoles". In: (2018), WEP2PO008. 3 p. DOI: 10.18429/JACoW-HB2018-WEP2PO008. URL: https://cds.cern.ch/record/2640326.