ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPJE067

APPLICATIONS OF PLACET2 TO THE CTF3 COMBINER RING

D. Pellegrini, EPFL, Lausanne, Switzerland and CERN, Geneva, Switzerland
D. Gamba, A. Latina, R. Corsini, CERN, Geneva, Switzerland

Abstract

The CTF3 Combiner Ring (CR) is an isochronous ring that employs RF-injection to combine multiple bunch trains (up to five) into a single one with higher bunch frequency. The length of the CR plays a critical role in obtaining the correct structure of the recombined train. PLACET2: the new recirculating version of the code PLACET, is particularly suited to simulate the operational scenario. In order to validate this code, two different case studies have been considered: ring-length variations due to optics scaling and vertical instabilities due to bunch-to-bunch wakefield effects. The response of the ring length to the optics scaling has been measured during the last CTF3 run. The instability has been compared with previous studies. The results are presented and discussed.

INTRODUCTION

At CTF3 the acceleration of an electron test beam is powered by an high-current electron drive beam that is decelerated in apposite power extraction units operating at 12 GHz [1]. The drive beam trains of bunches at 12 GHz are produced from longer, 1.5 GHz pulses, applying a factor 8 recombination. A first factor 2 is obtained in the delay loop [2]. The beam is then injected in the combiner ring using RF-deflectors. At every turn, new bunches are injected and interleaved with the one already turning.

The MAD-X model of the CTF3 combiner ring has been imported in PLACET2: the novel version of PLACET capable to handle recirculation [3]. A first measurement of the ring length response to the optics scaling has been performed and compared with the simulation. This has three main motivations: test the code predictions on a real machine, improve the understanding of the combiner rings optics, and demonstrate the possibility to manipulate the ring length possibly going beyond the capabilities of the wiggler magnet installed in the ring. This is particularly important to ensure a regular time structure of the combined beam that is crucial for an efficient deceleration.

The multi-bunch tracking capabilities of PLACET2 have been exploited reproducing the instability that was observed during the commissioning of the combiner ring, caused by a vertical mode trapped in the RF-deflectors.

METHODOLOGY OF THE LENGTH MEASUREMENT

The combiner ring length is measured using a button pickup or BPR: the beam-induced signal is multiplied by an external reference 3 GHz sine function. The phase slippage of the beam arrival time with respect to the 3 GHz reference becomes evident turn after turn as a modulation of the output signal. In the frequency domain the revolution frequency, f_{rev}, and its harmonics split into two sidebands whose distance, d_s, is determined by the fractional length, L_f, of the ring:

$$L_f = \pm \frac{d_s}{2 f_{rev}} \frac{c}{f_{ref}} \tag{1}$$

where c is the speed of light and f_{ref} is the 3 GHz reference frequency. The sign depends on the sidebands crossing; it can be determined empirically by varying the wiggler, whose effect on the fractional length is well understood.

The ideal machine setup for this measure consists of a 3 GHz beam from the gun, bypassing the delay loop. However, in order to not disturb other experiments, a factor 2 combined beam in the delay loop was kept. The train length was 140 ns, filling half of the ring and leaving enough time to completely switch off the RF deflector after the initial injection kick. The beam was kept circulating for approximately 100 turns.

The signal from the BPR was collected with an oscilloscope. The FFT of the signal was saved for the off-line analysis. A small dedicated C++ program has been written to clean the spectra, identify the peaks and compute the fractional length averaging over the available harmonics.

The quadrupoles and the dipoles currents where scaled independently monitoring the length variation. The data collected also comprehend a scan of the wiggler magnet.

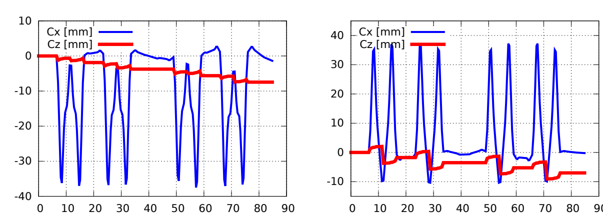

Figure 1: Horizontal and longitudinal bunch position computed for one turn in the combiner ring for two different scalings of the optics: left Q@95%, D@105%; right Q@105%, D@95%.

SIMULATION AND LOSSES

PLACET2 easily allows to track the bunch centroid in the reference frame of the ideal particle. Figure 1 shows the horizontal and longitudinal positions of a bunch for two possible scalings of the dipoles (D) and the quadrupoles (Q). Both the configurations decrease the length of the ring.

When scaling the optics by few percent, part of the beam may hit the vacuum chamber and be lost. This can affect the centroid position altering the result of the measurement.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPJE067

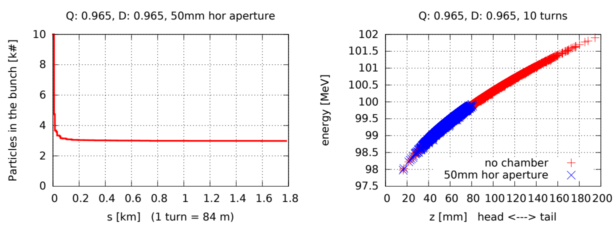

Figure 2: Left: losses profile for 20 turns in the ring. Right: longitudinal phase space after 10 turns.

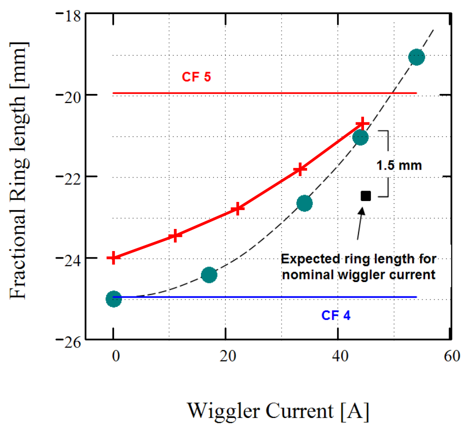

Figure 3: Effect of the wiggler current on the ring length. The red crosses are the new measurements, the blue dots are found in [4].

For this reason the aperture of the vacuum chamber has been included in the model. The model does not currently take into account element misalignments, orbit errors and correction. In order to obtain a loss profile compatible with the experience of the operators, the aperture has then been adjusted to 50×37 mm^2 in the model, while the physical is 90×37 mm^2. The acquisition of losses profiles for a better calibration of the model will be done in the next iteration of the measurement. An example of the aperture effect is shown in Fig. 2: most of the losses take place in the very first few turns and while the the high energies particles are lost, the centroid moves towards the head of the bunch.

WIGGLER EFFECT

A scan of the wiggler magnet was performed. The results presented in Fig. 3 are superimposed to the ones in [4]. The two sets of data have a distance of several years, with many machine shut downs and realignments in between. The difficulty to reach the length required for a combination factor 4 was observed in a previous run and is confirmed by the new measurement. This further justify the investigation of the possibility to reduce the ring length acting on the optics.

OPTICS SCALING

Figure 6 shows the length response to the scaling of the magnet strengths both simulated and measured. For a better

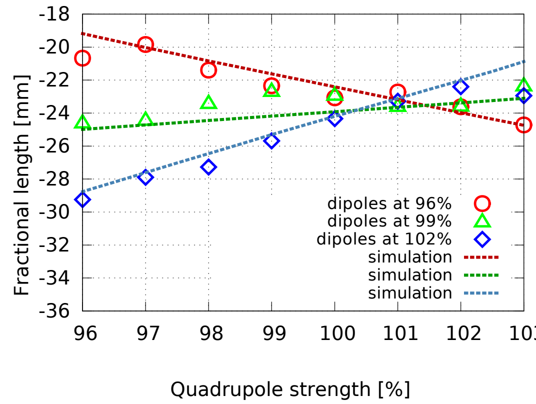

Figure 4: Ring length measured as function of the quadrupole strengths with the dipoles fixed at different values.

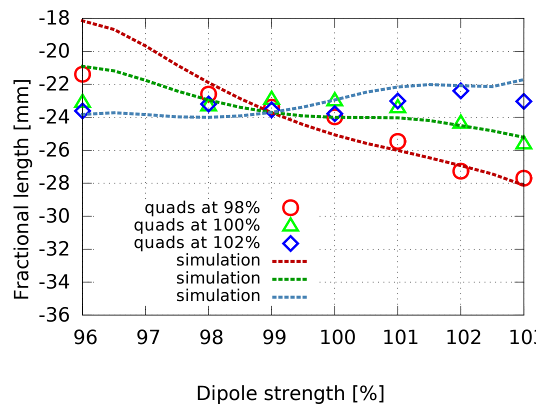

Figure 5: Ring length measured as function of the dipole strengths with the quadrupoles fixed at different values.

comparison, different sections of the surfaces are presented in Fig. 4 and Fig. 5. The dots are the experimental data while the dashed lines are obtained from the simulation. Given the know uncertainty on the beam energy in CTF3, its value has been slightly adjusted to improve the agreement.

Even if in the control room we never changed the beam energy, it is possible to inspect its effect by looking at the data where both quadrupoles and dipoles are scaled by the same amount. The measurement shows a very weak response of the ring length to this, which conflicts with the big T_{566} computed from the lattice model. Further measurements varying the energy of the beam may help to clarify the issue.

VERTICAL INSTABILITY IN THE OLD RF DEFLECTORS

During the commissioning of the combiner ring, back in 2007, a vertical instability appeared [5]. A Fourier analysis of the orbit excitation and the observation of a dependency on the bunch charge and train length, identified the cause in the RF-deflector. A new deflector design, employing antennas to extract the vertical mode, solved the issue in a short time. However the beam dynamics was investigated with an *ad-hoc* code written by D. Alesini [6].

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPJE067

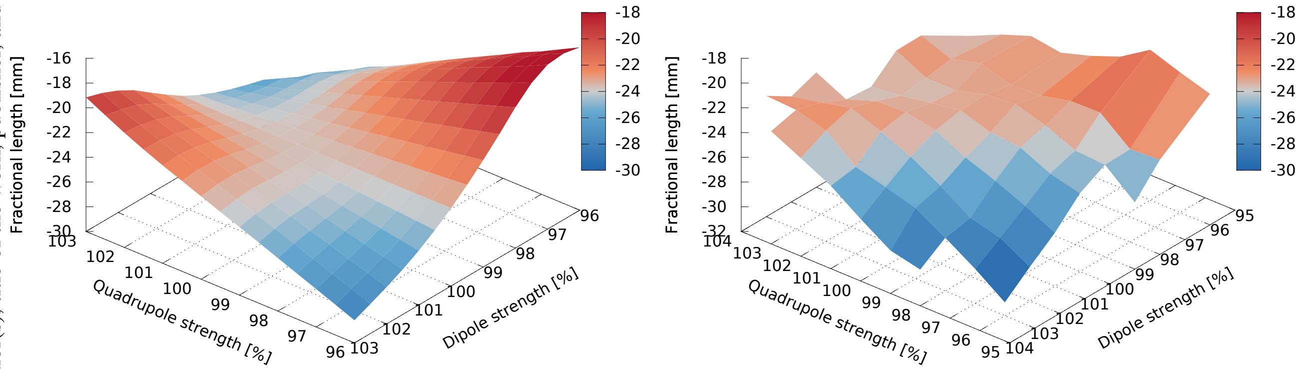

Figure 6: Responses of the CTF3 combiner ring length to quadrupole and dipole strengths variations. Left: PLACET2 simulations. Right: measured data.

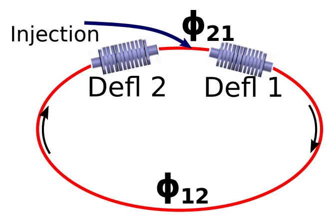

Figure 7: Scheme of the notation used: ϕ_{21} is the phase advance over the injection septum, while ϕ_{12} represent the phase advance in the complementary part of the ring.

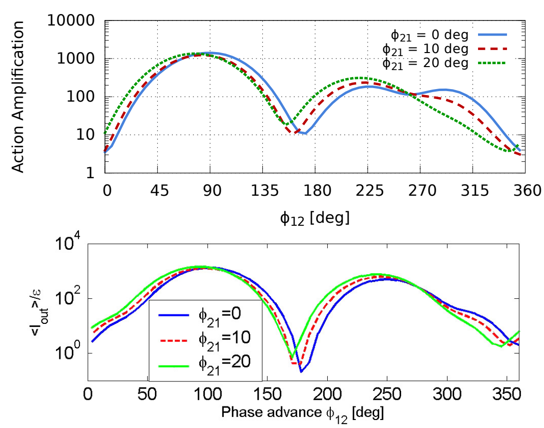

Figure 8: Action amplification due to the long-range wakefields as function of the phase ϕ_{21} computed with PLACET2 (top) and by D. Alesini (bottom).

PLACET2 has built-in multi-bunch tracking capabilities and can easily be employed to simulate the impact of vertical mode in the deflectors. Following the work of Alesini, we did not set up a dynamic injection with recombination, but we just let a beam circulate in the ring. The code of Alesini did not implement a full model of the ring: it took critical parameters as the the beta functions and the phase advances (see Fig. 7) as input. The phase advances ϕ_{12} and ϕ_{21} have been varied in the PLACET2 model by adding two matrices.

Figure 8 shows the action amplification due to the long-range wakefields as function of the phase ϕ_{21} (see Fig. 7). It has been computed injecting in the ring a 3 GHz train of 400 bunches with an initial offset of 1 mm, letting them circulate for 4.5 turns and calculating the ratio between their average action at the extraction and their initial action. The agreement between the PLACET2 computations and the results of Alesini is very good.

CONCLUSION AND OUTLOOK

A first measurement of the response of the combiner ring length to optics scaling has been performed. The possibility to decrease the ring length has been demonstrated. The PLACET2 simulations have been validated by the machine response, still further measures are required to better calibrate the losses and understand the effect of the energy error.

The multi-bunch capabilities of PLACET2 have been applied to the vertical instability caused by the vertical mode trapped in the RF-deflectors. The results published by Alesini have been reproduced.

ACKNOWLEDGMENT

The authors thank the CTF3 operation staff and in particular Frank Tecker and Piotr Skowronski for the help in the control room and the useful discussions.

REFERENCES

[1] G. Geschonke and A. Ghigo. *CTF3 Design Report*. Tech. rep. CERN-PS-2002-008-RF. CTF-3-NOTE-2002-047. LNF-2002-008-IR. Geneva: CERN, May 2002.

[2] R. Corsini et al. "Commissioning status of the CTF3 Delay Loop." In: *Proceeding of EPAC06*. Edinburgh, UK, 2006.

[3] D. Pellegrini, A. Latina, and D. Schulte. "PLACET2: a Novel Code for Beam Dynamics in Recirculating Machines." In: *These proceedings*. MOPJE068. Richmond VA, USA, 2015.

[4] R. Corsini et al. "Experimental Studies on Drive Beam Generation in CTF3." In: *Proceedings of the EPAC08*. MOPP010. Genoa, Italy, 2008.

[5] R. Corsini et al. "Fast Vertical Beam Instability in the CTF3 Combiner Ring." In: *Proceedings of the EPAC08*. MOPP011. Genoa, Italy, 2008.

[6] D. Alesini et al. "Beam instability induced by rf deflectors in the combiner ring of the CLIC test facility and mitigation by damped deflecting structures." In: *Physical Review Special Topics-Accelerators and Beams* 14.2 (2011), p. 022001.