ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPGW073

BEAM MANIPULATION USING SELF-INDUCED FIELDS AT THE SWISSFEL INJECTOR

S. Bettoni*, P. Craievich, E. Ferrari, R. Ganter, F. Marcellini, E. Prat, S. Reiche, C. Vicario
Paul Scherrer Institut, 5232 Villigen, Switzerland
A. Lutman
SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA
G. Penco
Elettra-Sincrotrone Trieste, Area Science Park, 34149 Trieste, Italy

Abstract

In the past years wakefield sources have been used to manipulate electron beams in accelerators. We recently installed corrugated structures of a total length of 2 m at the SwissFEL injector to test novel schemes for beam manipulations. We present simulations and early experimental results. We compare the model predictions with the measured data for the bunch energy losses and the kick factor, and show early results for the longitudinal phase space linearization and the production of current spikes.

INTRODUCTION

At SwissFEL [1, 2], the Free Electron Laser (FEL) facility at the Paul Scherrer Institut, we installed corrugated structures. The system comprises two structures DEH and DEV, each 1 meter long and orthogonally placed: in DEH the gap is closed moving the plates vertically, and in DEV horizontally. In each structure there are 3 corrugated plates with different geometries suitable to manipulate the electron bunches via wakefield interaction. SwissFEL is a normal conducting XFEL machine, starting with a photoinjector followed by compression and accelerator stages. There are two compression stages; the first one (BC1) operates at an energy of 300 MeV, the second one (BC2), located downstream of Linac1, operates at an energy of 2.1 GeV. Linac2 and Linac3 boost the beam energy up to 5.8 GeV to an energy collimator. From this section the beam is sent to an undulator line (hard X-ray branch), used to generate FEL radiation at a wavelength ranging from 0.1 nm to 0.7 nm. The three corrugations installed upstream of BC1 are suited for different kinds of beam manipulations, and they are indicated as dechirper, linearizer and two-color. The first is the same which will be used upstream of the soft X-ray branch of SwissFEL (presently in commissioning/installation) to remove the energy chirp residual from the compressions process [3, 4]. We plan to measure the energy loss and the kick factor of this structure to benchmark the model. The corrugation indicated as linearizer [5, 6] generates an energy loss along the bunch acting like a high harmonic of the main frequency of the structures upstream of BC1. This corrugation should have the same effect of a linearizing cavity, but without requiring RF power and with a reduced energy jitter. The latter corrugation, indicated as two-color [7], impinges a modulation along the beam longitudinal phase space. At the compression stages this perturbation of the beam longitudinal phase space produces current spikes separated in time and energy. The resulting electron bunches present two (or more) short high current spikes suitable to generate pairs (trains) of X-ray pulses to perform pump/probe experiments. In this proceeding we will concentrate on the last two corrugations. More detailed description of the geometry of these corrugations can be found in [8].

* simona.bettoni@psi.ch

NUMERICAL SIMULATIONS

At SwissFEL we have the possibility to illuminate the photocathode using different shapes of the laser longitudinal profiles: a flat-top distribution [9], or a single Gaussian with a tunable rms length, σ. Figure 1 shows the wake potential obtained with the analytical model using CST Studio [10], and ECHO2D [11] codes assuming the different bunch shapes for the corrugations of the linearizer and two-color. The analytical model differs from the numerical simulations because it is valid only assuming some hypotheses on the geometry of the structures not fully fulfilled in our case (ratio of the height and the period of the corrugation). The agreement between CST and ECHO2D is so satisfactory that either code is sufficient to simulate the problem.

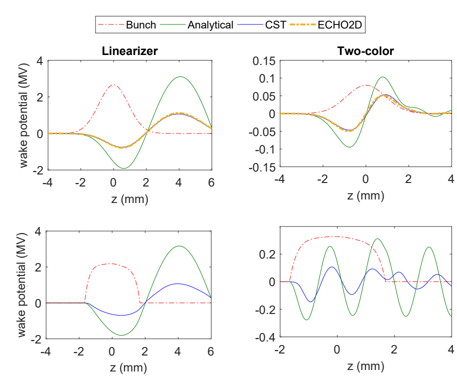

Figure 1: Wake potential obtained assuming Gaussian and flat-top bunch profiles. We assumed a Gaussian bunch with σ = 0.9 mm and a flat-top distribution with FWHM of 10 ps. For both cases we used a bunch charge of 200 pC, which is the maximum design charge of SwissFEL.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPGW073

EXPERIMENTAL RESULTS

In the following subsections we will describe the beam measurements performed at the injector downstream of BC1, and at the energy collimator at the entrance of the undulator line. These sections are equipped with a Transverse Deflecting Cavity (TDC), used to impose a time-dependent kick along the bunch to map the longitudinal coordinate of the beam into the vertical coordinate at a downstream screen. The bunch longitudinal phase space is measured by imaging the streaked beam on a screen installed downstream of a bend dispersing the bunch along the horizontal direction depending on the energy of the particles. Using the TDC and a quadrupole scan technique we measure the horizontal slice emittance and the mismatch parameter as function of the bunch temporal coordinate.

Linearizer

We measured the beam mean energy loss and the kick factor to characterize the longitudinal and the transverse wakefield of the structures, respectively. To measure the loss factor we recorded the variation of the orbit of the beam in a dispersive section. We repeated the measurements changing the gaps of the plates. We preferred to use the Synchrotron Radiation Monitor (SRM) located at BC1 [12] to perform the measurements, because a Beam Position Monitor (BPM) at BC1 or at the spectrometer arm might have suffered of resolution problem going the beam off-axis during the measurement. Figure 2 shows the energy change of the beam as a function of the gap for the two structures compared with the numerical simulations.

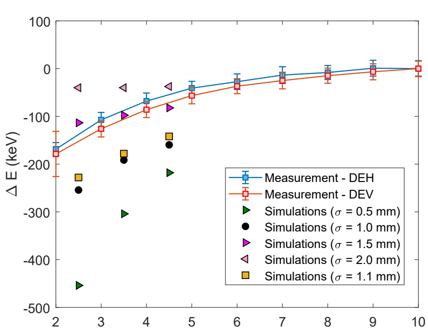

Figure 2: Measured mean energy change per structure as a function of the gap compared with the simulated results. The bunch has a charge of 200 pC, a Gaussian longitudinal shape with σ equal to 1.1 mm (measured electron bunch length).

To measure the kick factor we recorded the variation of the orbit closing one structure and displacing the center of the system farther and farther from the "on-axis" beam trajectory inside the structure. The results are shown in Fig. 3.

The measurements shown in Fig. 2 and that in Fig. 3, which depend on the longitudinal and the transverse wake, respectively, give similar results: we have a disagreement

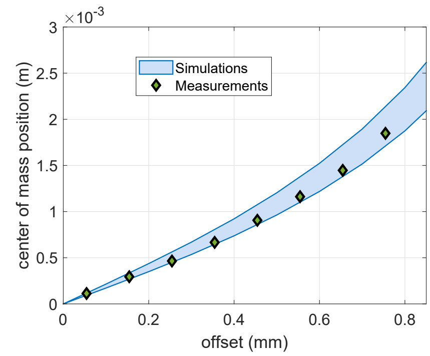

Figure 3: Orbit deviation of the electron bunch as a function of the transverse offset in the structure (kick factor) compared to the simulations (assumed charge in a range between 160 pC and 200 pC).

between the simulation and the measurement. We suspect we have a different charge of the bunch. More investigations to understand the reason for the discrepancy are needed, but this did not prevent us to test the beam linearization.

We used the corrugation to partially linearize the beam longitudinal phase space downstream of BC1. We reduced the energy change of the linearizer cavity by about 40 %, and we used the passive structures to compensate for it. Figure 4 shows the centroid positions of the slices along the bunch imaged on a screen in a dispersive arm and streaked using the TDC, as aforementioned.

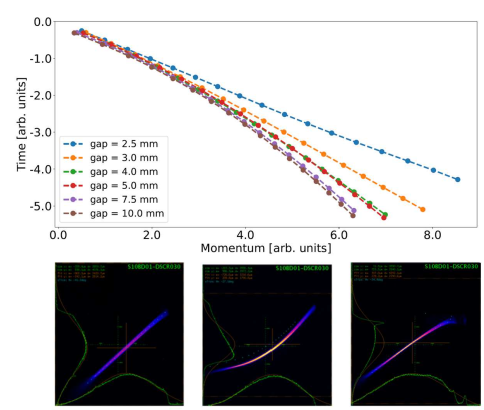

Figure 4: Measured beam longitudinal phase space. Top plot: centroid position of slices along the bunch for different gaps. Bottom plot: images of a streaked (in vertical) electron beam in a dispersive (in horizontal) section at the nominal setting of the linearizing cavity (left), with the reduced power of the linearizing cavity (center), and with the reduced power of the linearizing cavity and the passive structures at gap = 2.5 mm (right).

As shown in Fig. 4, we successfully linearized the beam longitudinal phase space at a reduced power of the linearizing cavity using the wakefield excited by the bunch itself passing through the structures with a gap of 2.5 mm.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPGW073

Two-color

We used the two-color corrugation to generate two spikes along the bunch duration with different electron energies to produce an electron bunch suitable for production of two-color XFEL pulses for pump/probe experiments.

We generated electron current profiles with two spike distributions, by using the single Gaussian laser profile and the flat-top distribution as well. In both cases we obtained two spikes in current separated in energy, which lase at different wavelengths. The way in which the two spikes are obtained is different depending on the laser profile shape. In case the initial bunch shaping is Gaussian the spike at the tail is generated by the interaction of the electron bunch with the wakefield of the passive structures, whereas the spike at the head is coming from the compression (the design current profile already presents a spike on the bunch head at the energy collimator). On the contrary, in case the bunch profile is a flat-top both the spikes are induced by the self interaction of the beam with the wakefield of the structures. The laser profile assumed in [7] is the flat-top, which in theory should give the best beam quality and therefore the more intense FEL signal, but we are in the process to experimentally compare the two approaches.

We obtained the expected current profile downstream of BC1, and we preserved the structure of the bunch down to the energy collimator, as shown in Figure 5. We are presently

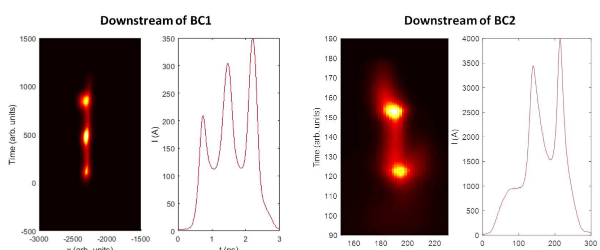

Figure 5: Image of the beam streaked (in vertical) on a screen downstream of BC1 at 300 MeV (left), and at the energy collimator at 5.8 GeV (right plot), and corresponding current profiles. In this case we present the measurements done using the flat-top distribution.

addressing the problem of a slice emittance increase at the location of the current spikes downstream of BC1. An example of the measured slice emittance and optical mismatch along the bunch is shown in Fig. 6. The measured slice emittance increase may be explained by a slight difference of the quadrupolar component of the wakefield of the DEH and DEV structures (the optics along the two structures is not exactly the same). In this case the optics at the location of the two spikes is not the design one, and this may generate a slice emittance increase along the bunch during the compression, as already found in the past [13]. This is an aspect which must be addressed since it may impact the FEL performance. In the near future we plan to further

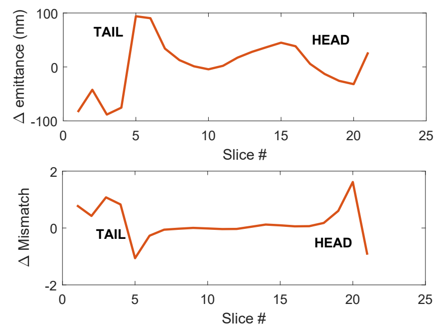

Figure 6: Variation of the emittance and mismatch along the bunch in the configuration with the passive structures closed (gap = 3 mm) with respect to the case where the structures are open.

investigate and optimize the beam quality to maximize the intensity of the FEL signal.

ACKNOWLEDGMENT

We would like to thank all the technical groups, which make SwissFEL operate.

CONCLUSIONS

We experimentally tested two beam manipulation schemes using wakefields excited by the bunch itself passing through corrugated structures. Using one corrugation we linearized the beam longitudinal phase space significantly, reducing the power of the linearizing cavity. We observed some discrepancies between the simulations and the measurements, presently still under investigation. This scheme is in principle an alternative way to linearize the compression. We used the second corrugation to generate two spikes in current long the bunch to produce lasing at different photon energies. A future campaign of measurements will be dedicated to improve the beam quality to maximize the FEL intensity. This scheme may be used to perform pump and probe experiments at SwissFEL.

REFERENCES

[1] R. Ganter ed., "SwissFEL Conceptual Design Report", PSI, Villigen, Switzerland, Tech. Rep., 2011.

[2] C. Milne, et al., "SwissFEL: The Swiss X-ray Free Electron Laser", *Applied Sciences*, vol. 7, p. 720, 2017.

[3] S. Antipov, et al., "Experimental Demonstration of Energy-Chirp Compensation by a Tunable Dielectric-Based Structure",*Phys. Rev. Lett.*, vol. 112, p. 114801, 2014.

[4] P. Emma, et al., "Experimental Demonstration of Energy-Chirp Control in Relativistic Electron Bunches Using a Corrugated Pipe", *Phys. Rev. Lett.*, vol. 112, p. 034801, 2014.

[5] G. Penco, et al., "Passive Linearization of the Magnetic Bunch Compression Using Self-Induced Fields", *Phys. Rev. Lett.*, vol. 119, p. 184802, 2017.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPGW073

[6] P. Craievich, "Passive longitudinal phase space linearizer", *Phys. Rev. ST Accel. Beams*, vol. 13, p. 034401, 2010.

[7] S. Bettoni, E. Prat, S. Reiche, "Two-color Beam Generation Based on Wakefield Excitation", *Phys. Rev. Acc. Beams*, vol. 19, p. 050702, 2016.

[8] S. Bettoni *et al.*, "Beam Manipulation Using Self-Induced Fields in the SwissFEL Injector", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 3401–3404. doi:10.18429/JACoW-IPAC2018-THPAK074

[9] A. Trisorio, P.M. Paul, F. Ple, C. Ruchert, C. Vicario, and C.P. Hauri, "Ultrabroadband TW-class Ti:sapphire laser system with adjustable central wavelength, bandwidth and multi-color operation", *Opt. Express*, vol. 19,p. 20128, 2011.

[10] CST Studio Suite. https://www.cst.com/.

[11] I. Zagorodnov, Electromagnetic code ECHO.

[12] G. L. Orlandi *et al.*, "Bunch-Compressor Transverse Profile Monitors of the SwissFEL Injector Test Facility", in *Proc. 1st Int. Beam Instrumentation Conf. (IBIC'12)*, Tsukuba, Japan, Oct. 2012, paper MOPB82, pp. 271–275.

[13] S. Bettoni, M. Aiba, B. Beutner, M. Pedrozzi, E. Prat, S. Reiche, and T. Schietinger, "Preservation of low slice emittance in bunch compressors", *Phys. Rev. Acc. Beams*, vol. 19, p. 034402, 2016.