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BEAM MANIPULATION USING SELF-INDUCED FIELDS IN THE SwissFEL INJECTOR

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Abstract

Several possibilities of manipulating the electron beam using sources of wakefield are being explored. Wakefield have been successfully used to remove or enhance the energy chirp residual from the magnetic compression to control the free electron laser bandwidth (dechirper), to linearize the compressed beam (linearizer), to generate more bunches to produce two color mode, and to perform experiments of wakefield acceleration. At the SwissFEL injector we plan to install 2 m long system to accommodate sources of wakefield with different periodicities, each of them associated with one of the discussed beam manipulation. In this paper we summarize the design and the characterization of the system and the planned activities.

INTRODUCTION

Modern day light sources of the 4th generation, which convert the energy stored in a relativistic electron bunch to coherent intense radiation pulses in the X-ray region using the mechanism of the Free Electron Laser (FEL) facilities [1], rely on the generation of a high brightness electron bunch with a very small spread in the electrons positions, momenta, and energies, and the preservation of those quantities during acceleration and compression. Typical beam parameters, which are used for the SwissFEL facility [2] at the Paul Scherrer Institut, are an RMS pulse duration of 20 fs or less and a normalized transverse emittance of about 300 nm. The peak current of 3 kA is achieved by compression in two stages by means of run-time differences in magnetic chicanes. This schematic layout of a facility with beam generation, two stage compression, main acceleration to GeV beam energies and injection in the periodic magnetic field of the FEL is shown for the case of SwissFEL in Fig. 1.

Fields, which are generated by the bunch and act upon the bunch itself, are called wakefields and offer the benefit of providing high field strengths while being automatically synchronized to the beam itself. This is explicitly sought-after in plasma beatwave acceleration projects [3] or acceleration in dielectric structures [4]. By the nature of self-interacting fields no net energy gain is possible. However energy or momenta can be transferred within the bunch, which opens up the possibility to manipulate the electron bunch distribution in a controllable manner.

Although the design of FEL facilities is aimed to reduce the magnitude of wakefields in the machine to a minimal level, in the last years several projects used or plan to use the longitudinal or the transverse wakefield of special structures to manipulate the electron beam. The longitudinal wakefield can be used to compensate the chirp residual from the bunch compression [5, 6], or passively linearize the longitudinal phase space [7] and [8] instead of using a high harmonic cavity. The transverse wakefield can be used to impose a time-dependent kick on the bunch to determine the longitudinal beam profile without using a transverse deflecting structure [9]. The longitudinal wakefield may be used to select different sections along the bunch length to lase producing two or more colors FEL pulses [10, 11].

We will install in Summer 2018 a 1 m plus 1 m corrugated structure with several corrugation periods corresponding to different impedances to carry on several studies. In the following, we describe the design and the most important steps in the manufacturing process of the device, the schedule, and the experiments that we plan to undertake. We then discuss the numerical simulations in comparison to the expectations of the analytical model, before finally drawing some conclusions.

PASSIVE DEVICES FOR BEAM MANIPULATION

We plan to use three corrugations mounted on a common support to verify the model of the wakefield using the same corrugation which will be used to remove the chirp residual from the bunch compression in the high energy section of SwissFEL upstream of the Athos line (*dechirper*). In particular we want to verify the effect of the quadrupole wakefield excited by the beam passing through the device for the typical small emittance we obtain at the SwissFEL injector (below 200 nm for 20 A peak current).

The longitudinal wakefields have been already used to remove the linear part of the energy chirp residual from the bunch compression, making the higher order modes of the longitudinal phase space dominant. A special design of the corrugated surface (*linearizer*) can be tuned to have a characteristic wavelength of the wakefield longer than the full bunch length, in such a way that the non-linear terms of the longitudinal phase space may be also controlled. This device can replace a high order RF cavity [12], an essential part in the compression of the bunch down to femtosecond pulse lengths. The routine use of such a device in a facility has still to be demonstrated; in particular we want to prove that it can be adjusted to different bunch lengths, charges and that it may be used to provide a more stable FEL beam.

With the proper choice of the wall corrugation a synchronous wakefield can be exited with a period length which is adjusted to half the full bunch length (*Two-color*). Because two periods of the wake fit within the full bunch length the chirp is locally enhanced at two locations. These enhance-

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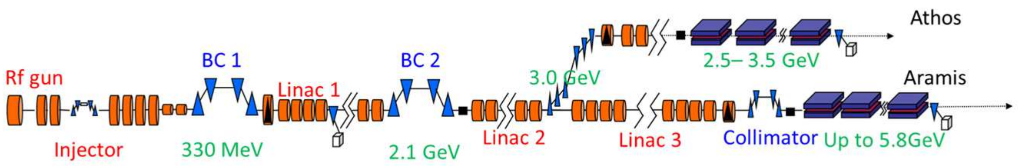

Figure 1: SwissFEL schematic layout.

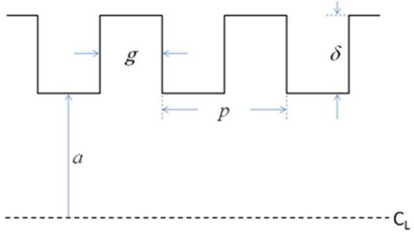

Figure 2: Schematic view of a generic corrugation.

ments yield higher current in the compression, transforming a smooth current profile into two well defined current spikes. This offers the capability to operate the FEL with two distinct pulses and the possibility of tuning the time and the energy separation among them for pump-and-probe experiments. This scheme compared to others maximizes the photon pulse energy because the entire bunch lases and the beam is not degraded at the low energy section of the machine. More details can be found in Ref. [13].

Each of these experiments requires a different periodicity of the corrugation. In Table 1 the parameters corresponding to the different cases are reported with reference to Fig. 2.

Table 1: Geometries for the different experiments using the corrugated plates. The meaning of the parameters are reported in Fig. 2.

	Linearizer	**Dechirper**	**Two-color**
g (μm)	1500	250	220
p (μm)	2000	500	500
δ (μm)	1500	250	100
a (mm)	1.50	1.25	1.50

The first two corrugations will be also used to continue the experiments to passively streak the electron beam improving the resolution obtained in the past using a 10 cm wakefield source [9]. For this kind of measurements it is essential for a correct reconstruction of the bunch longitudinal profile that the wake potential is monotone along the full bunch length.

The plates are accommodated on two orthogonal plates long 1 m each and movable to make possible to switch from one to another corrugation. The distance among them has been chosen to have a negligible effect of one to the neighbors when the beam excites a specific wakefield (10 mm width and 5 mm separation among the corrugations). The picture of one of the structures is shown in Fig. 3.

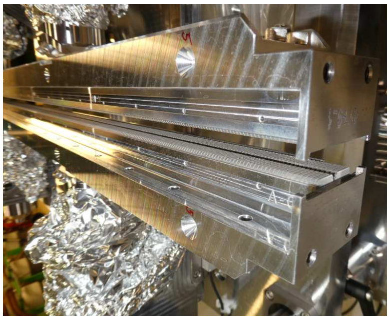

Figure 3: 1 m passive device (gap in the vertical plane) which will be installed at the SwissFEL injector. Two over the three corrugations are also visible.

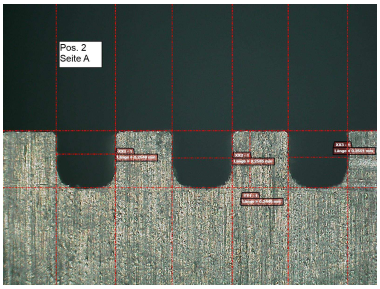

Figure 4: Corrugation shape obtained with the technique of the wire cut.

The two jaws of the system are driven by two independent motors in order to adjust the distance between corrugation and beam. The one meter long corrugation array consists of five consecutive aluminum blocks sitting on a precisely machined aluminium supports. The support will provide an overall flatness of the structure of less than 50 μm over 1 m. The *linearizer* corrugation geometry is done by wire erosion using a 0.1 mm diameter wire (see Fig. 4). The other two geometries were milled to achieve even finer resolution (see Fig. 5). The devices will be installed in August 2018 at the SwissFEL injector, and the first experiments are foreseen in September of the same year.

NUMERICAL SIMULATIONS AND ANALYTICAL MODEL

We run numerical simulations using the code CST Particle Studio to verify the validity of the analytical model. We used a Gaussian and the flat-top beam longitudinal distribution as well to model our electron bunch. The first is a possible option for the laser at SwissFEL, and the latter is

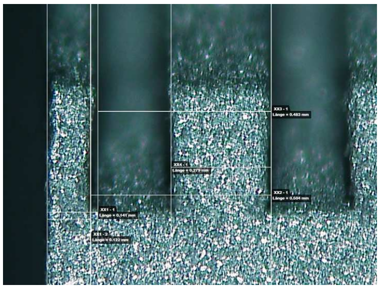

Figure 5: Aluminum corrugation geometry obtained by milling. This geometry correspond to the 0.5 mm period and 0.25 mm groove depth.

the present design beam shape. We assumed a sigma for the Gaussian pulse of 0.9 mm, and a length for the flat-top of 10 ps full width half maximum. For the three geometries reported in Table 1 we compare the analytical calculations, obtained doing the convolution of the longitudinal bunch profile with the wakefield point charge of the synchronous mode [14], and the time domain code. In Fig. 6 the results of the calculations are shown. The discrepancies between the analytical and numerical wake potentials are expected because the corrugation dimensions become comparable to the gap of the two plates and assumptions in [14–16] to estimate the analytical solution are no longer applicable.

CONCLUSIONS

Longitudinal and transverse wakefield may be used to manipulate and diagnose the bunch, respectively. At SwissFEL we will install in Summer 2018 a system with different corrugations to excite wakefield of several periodicity. This will allow to modify the longitudinal phase space, and to verify the effect on the bunch on the bandwidth and stability of the generated FEL pulse. We discussed in this paper the expected wakefields assuming an analytical model compared to the CST Particle Studio simulations. We plan in 2018-2019 to have a full characterization of the longitudinal and transverse wakefield obtained.

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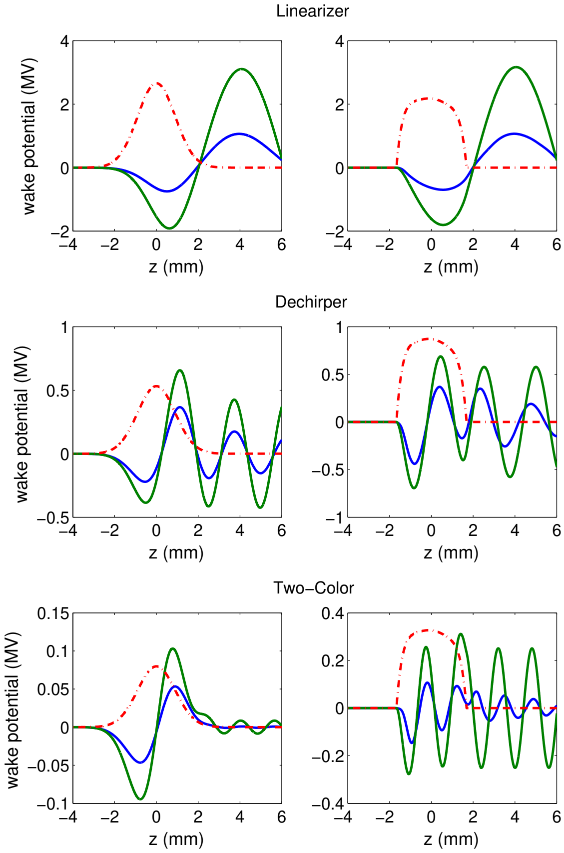

Figure 6: Comparison of the analytical calculations with the 3D time domain code. The comparison is repeated assuming both a Gaussian and a flat-top charge distribution as longitudinal profile. For all cases the charge is 200 pC and the length of the passive structure is 2 m. Legend: red lines: charge distribution, blue lines: numerical (CST), green lines: analytical.

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