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PROSPECTS FOR LONGITUDINAL PHASE-SPACE MEASUREMENTS AT THE MAX IV LINAC

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Abstract

Knowing the longitudinal phase space of an electron beam is one of the most important and crucial issues in short-pulses linacs. To achieve this task expensive and rather complicated setups (like transverse deflecting cavities) are usually implemented. The MAX IV linac is a 3 GeV accelerator which will be used to inject into two rings and to drive a short pulse facility. Nevertheless, a more deep understanding of the beam quality would be useful especially in view of an upgrade as FEL driver. Another interesting aspect is to evaluate how the double-achromat bunch compressors are performing. We are studying how to implement off-phase acceleration: one part of the linac will be set at zero-crossing phase and the following transfer line could be used as energy spectrometer to retrieve the bunch profile. In the present configuration of the MAX IV linac this procedure will allow to check the bunch length after the first bunch compressor. Since it is work in progress, in this contribution we present a sketch of the measurement and the feasibility of the method will be explored by means of simulations.

INTRODUCTION

The measurement of the longitudinal phase-space in short-pulses linacs turned out to be one of the key features in order to fine-tune the machines and in case of Free Electron Laser drivers, also to control the lasing process [1]. At SLAC it has been demonstrated during the last couple of years that the help of the transverse deflecting cavities is invaluable [2]. Also in other facilities like FERMI@elettra [3] and the SwissFEL [4] the use of transverse deflecting cavities is very extensive. The MAX IV project [5] is a synchrotron facility in Lund (Sweden) currently under construction and consisting in two storage rings and a linac which serves as injector for the rings and for a Short Pulse Facility (SPF) [6]. The linac is equipped with two guns, a thermionic gun for filling the rings and a photocathode gun, which will produce very short electron bunches for the SPF (see Fig. 1). The linac is currently under commissioning (Spring 2014) and the following step will be to commission the storage rings after their installation. The combination of photocathode gun and the linac is also suitable for driving a Free Electron Laser (FEL), which is now in the strategic plan of the MAX IV laboratory. It is foreseen to extend the linac energy to 5-6 GeV [7] and produce radiation in the Ångström range [8]. Although the performance of the injector are expected to be suitable for a FEL, however, in its initial phase, the MAX IV linac does not have the necessary diagnostics for checking the longitudinal phase space, which is crucial for running the FEL process. Therefore we are investigating other methods to access the parameters that need to be checked (see also [9]) and also to calibrate THz detectors that will be installed for relative and parasitic measurements.

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THE MAX IV LINAC AND ITS BUNCH COMPRESSORS

The MAX IV linac consists of 39 S-band structures double-coupled to klystrons and fed by SLED cavities. The maximum repetition rate is 100 Hz. The peculiarity of the MAX IV linac consists of two bunch compressors with the double achromat configuration [10]. The first bunch compressor (BC1) is located at 260 MeV and the second one at 3 GeV. In contrast with normal chicane compressors, this scheme has positive and fixed R_{56}. Therefore the RF slope used for accelerating the electrons must be the falling one and the off-crest tuning is used to change the compression factor. As the positive T_{566} takes care of the linearization in the achromats, there is no need of higher order cavities in the linac. The effect of the bunch compressors is to shorten the electron beam from about 10 ps (coming from the photocathode gun) to 5–0.3 ps after BC1 and to 500–10 fs after BC2. The two different compressions are foreseen for high and low peak current operation [11].

During the commissioning of the machine, it will be essential to check the optics in the bunch compressors and verify that they work as expected. The knowledge of the bunch length after BC1 would allow to calibrate the THz detectors which are relative diagnostics. They would work online also during the operation of the SPF when it would not be possible to bend the beam into the transfer lines for checking the compression. Along the linac there are two extraction points, one at 1.5 GeV and one at 3 GeV, as it can be seen in Fig. 1. The first part of both transfer lines to the rings can be used as energy spectrometer. There are in fact beam position monitors before and after the main bending magnet, as well as YAG screens.

THE ZERO-PHASE METHOD

The method of measuring the longitudinal bunch profile with off-phase RF acceleration has been described and implemented since long time [12–15]. The idea is to run some of the last RF structures of the linac at zero phase, to let the electrons experience a different field depending on their arrival time. In this way the longitudinal distribution of the electron beam is translated into a distribution in energy, which can be revealed with an energy spectrometer. In the case of MAX IV linac the implementation is quite straightforward. Since there are no accelerating structures after the second bunch compressor, the method can be applied only in the first part of the linac, to check the compression after the

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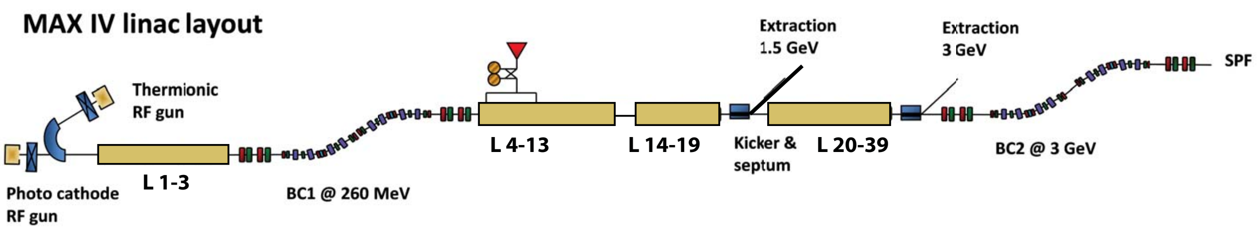

Figure 1: The current layout of the MAX IV linac with two bunch compressor and the extraction lines at 1.5 and 3 GeV.

first bunch compressor. The relative elongation of the beam can be seen with the YAG screen in the 1.5 GeV transfer line.

Simulations

Ideally the linac can be divided into three parts: the first three accelerating structures before BC1, the next ten structures after BC1 (L 4–13 in Fig. 1) and the following six structures before the extraction point for the 1.5 GeV linac (L 14–19). We performed numerical simulations of the setup using ELEGANT [16] and starting with 100 pC electron beam charge. In our simulation we found an optimal configuration for the RF phases in the three parts of the linac and we can compare different compressions.

The first case under study is a high-compressed beam. The first three sections are run about 36 degrees off crest in order to have the necessary energy chirp before entering the bunch compressor. After BC1 the electron beam energy is around 260 MeV and the electrons should gain more energy in order to be extracted in the transfer line, therefore the next ten accelerating structures are set on crest. After that the remaining six structures before the transfer line are run at zero phase to get the time–energy correlation. Figure 2 shows the longitudinal phase-space after the last accelerating structure.

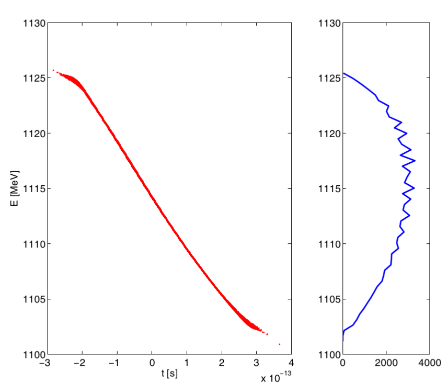

Figure 2: Longitudinal phase-space at the end of linac 19 for the high-compressed beam. The phase of the pre-BC1 structures is +36 deg.

The second case is a under-compressed beam, obtained changing the RF phase in the structures before BC1 from +36 deg to +24 deg. The longitudinal phase-space before the extraction line is displayed in Fig. 3

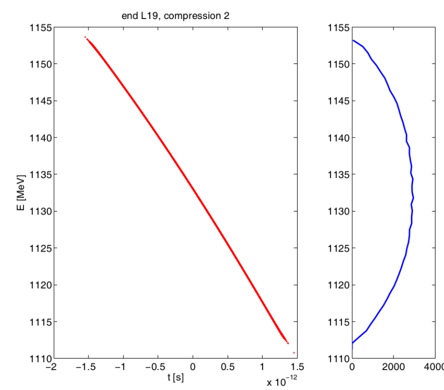

Figure 3: ELEGANT simulation of the under-compressed 100 pC beam. The phase of the pre-BC1 structures is +24 deg.

The bending magnet in the transfer line for the 1.5 GeV ring has been designed also to work as energy spectrometer. Given a dispersion of about 0.45 m, the expected energy resolution is on the order of 10^{-5}. The bending magnet is followed by a short drift where is sitting a YAG screen which can be used to image the dispersed beam. Figure 4 displays the transverse (x–y) profile of the electron beam as it will be seen inserting the YAG screen in the transfer line.

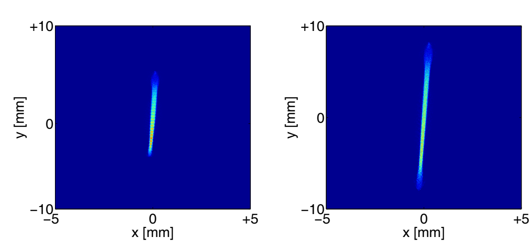

Figure 4: ELEGANT simulation for the 100 pC beam. The picture shows how the beam will look like at screen located in the extraction line. The left figure refers to the high-compressed case, while the right one to the under-compressed beam.

The method does not allow to see the full longitudinal phase space, but gives an estimate of the bunch length and it could be used during the commissioning to benchmark the operation of the first bunch compressor. As an additional

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feature, this method can be used to see the transverse wake-fields acting on the beam when this is displaced in the linac. Figure 5 shows the reference beam and the beam with the tail kicked by the wakefields when the structures are displaced 3 mm in the horizontal direction.

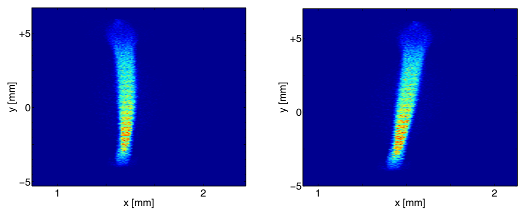

Figure 5: Transverse profile at the YAG screen. Comparison between zero displacement (left) and 3 mm displacement (right) and the effect of the transverse wake-fields.

PROSPECTS FOR FEL DIAGNOSTICS

The requirements for a linac that drives a Free-electron laser are more pressing in terms of electron beam performance and stability, not only in the transverse plane (emittance) but also longitudinal energy spread and chirp. Moreover the parameters have to be not only stable in a certain configuration, but one should also be able to tune the machine for different settings depending on the desired mode of operation. As previously stated, the MAX IV linac is not equipped with a transverse deflecting cavity but following the idea in [17], we could anyway achieve an estimate for the bunch length at the end of the linac, i.e., after BC2. In our configuration there are only two bunch compressors and no diagnostic chicane, so the transport matrix is simpler between the extraction point at 1.5 GeV and the end of BC2. The bunch length at the end of the linac has three major contributions: first, from the accelerating structures in the linac 2 section (which can be tuned in terms of voltage and phase); second, from the wakefields, contribution that can be estimated; third, from the initial bunch length after linac 1, that can be measured in the transfer line at 1.5 GeV. The contribution from the longitudinal wakefields is already under study (see [9]) and preliminary estimations show that for low charge (25 pC) electron bunches the contribution to the total energy spread is only few percent. Therefore using even lower charges (10 pC) the wakefield contribution could be neglected.

CONCLUSION

In this paper we showed preliminary ideas of how we could measure the longitudinal bunch profile after the first bunch compressor in the MAX IV linac using the zero-phase method. In order to get the full picture, a transverse deflecting cavity at the end of the linac would be envisaged, especially in connection with the upgrade of the injector into a driver for a FEL. Nevertheless we think that we could estimate the bunch length at the end of the linac using the second approach described in the paper. This is an on-going study and we expect to carry on more detailed simulation and quantitative estimations in the next future.

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