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CHARACTERIZATION OF LONGITUDINAL WAKEFIELDS IN THE MAX IV LINAC

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Abstract

In the second part of 2014, the 3 GeV linac at the MAX IV laboratory will enter its commissioning stage. Equipped with two guns, the linac will act as a full energy injector for the two storage rings and at the same time provide high brightness pulses to a Short Pulse Facility (SPF). Compression in the linac is done in two double achromats with fixed R56 that relies upon the RF phase introduced energy chirp, which in this case is strongly enhanced by the longitudinal wakefields. Since the longitudinal wakefields play a major role in the compression and bunch shaping they need to be carefully investigated during the commissioning.

In this proceeding we will discuss a measurement technique that will be used during commissioning to characterize the longitudinal wakefields in the MAX IV linac and their precise effects on e.g. the bunch shape and the energy spread. Predictions obtained from particle tracking will be presented.

INTRODUCTION

The new synchrotron facility at the MAX IV Laboratory [1] is currently under construction in Lund, Sweden. The facility consists of a 300 m long S-band linac injecting electrons to two storage rings (1.5 and 3 GeV) and a short pulse facility. A Free Electron Laser (FEL) is considered as a second development stage [2, 3]. The MAX IV linac has now entered its conditioning phase and commissioning is planned for early fall this year.

General Layout of the MAX IV Linac

Since the linac serves as injector for both storage rings and the SPF, it is designed to frequently alternate between two operation modes and uses two different guns. The thermionic gun will be used during injection and top-up of the rings whereas the photocathode gun will serve the SPF.

Magnetic Double Achromat Bunch Compressors

To control the compression of the beam there are two magnetic double achromat bunch compressors (BCs) in the linac, BC1 situated at 260 MeV and BC2 at 3 GeV, see Fig. 1. More precisely, each BC consists of two achromat structures each including four bending magnets, a series of quadrupoles and a sextupole, forming an arc [4]. Unlike the commonly used magnetic chicane BCs, the double achromats have a positive R56. In addition, the R56 is fixed, hence the compression achieved in the BCs depends upon the RF voltage slope in the accelerating structures prior to the compressors. As the achromats have a positive R56 the acceleration is done on a falling RF slope as a function of time.

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Energy Spread and Longitudinal Wakefields

Short range wakefields are induced when charged particles pass through a varying geometric structure, for instance an RF cavity structure. The wakes affect the beam dynamics both longitudinally and transversely and may give rise to beam instability. The wakefield model used in the official MAX IV linac elegant [5] latticel is based on an analytical model [6–8]. The longitudinal wakefields plays an important role in the compression [9] since they contribute to an energy spread within the same bunch. The wakefields induced by the particles in the head of the bunch lead in fact to an energy loss in the tail. In the achromat compression scheme the wakes enhances the already existing energy chirp from the RF slope and therefore lead to a stronger compression. In the MAX IV linac the compression and thus the final peak current of the beam alters strongly with minor changes in the energy chirp. As a result, it is important to characterize the longitudinal wakefields that influences this chirp.

Using the particle tracking code elegant, we will present one method making it possible to identify the longitudinal wakefields and its effect on the beam. At a later stage, the corresponding measurements on the real machine can be performed in order to verify the analytical wake model used in the simulations.

METHOD

A transvers deflecting cavity (TDC) would be the optimal tool to characterize wakefields in the linac since it makes it possible to image the longitudinal phase space of the beam directly. Simulation of the corresponding longitudinal phase space of a strongly compressed 500 pC beam, after linac section 1 and linac section 2 can be visualized in Fig. 2. Using a TDC we would be able to experimentally generate similar figures, but such a devise is not included in the MAX IV linac at present. Therefore, to investigate to what extent the longitudinal wakefields actually contribute to the energy spread in the bunch, the dipole magnets in the ring extraction transfer lines, each followed by a YAG screen, are used as spectrometers. The screens, situated in equally dispersive areas, will then show the projected relative energy spread of the beam.

The compression of the bunch is tuned by adjusting the phase in the linac structures before BC1 and the particles are accelerated up to 1.5 GeV through linac section 1. By bending the beam into the first transfer line it is possible to measure the relative energy spread at screen 1 (YAG1.5) which from now on will serve as a reference.

In a second step we let the same 1.5 GeV beam simply propagate i.e. without adding any energy, through the linac 2 section as well. Since the RF voltage in the accelerating

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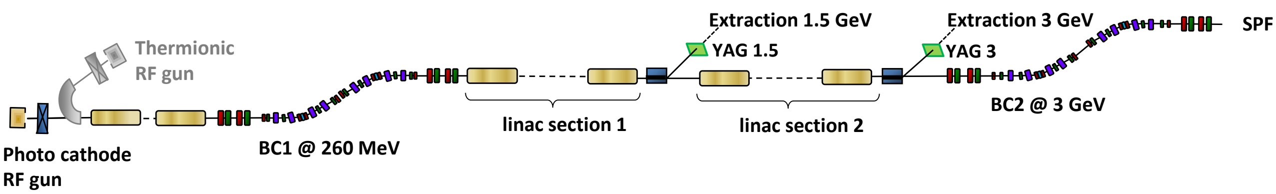

Figure 1: Schematic layout of the MAX IV linac.

structures is off, it is clear that the energy spread induced in the second linac section purely results from longitudinal wakefields. The beam is then extracted into the second transfer line and can be observed on screen 2 (YAG3).

Finally, by comparing the difference in relative energy spread at screen 1 and 2 the direct influence from the longitudinal wakefields generated in the second linac section can be deduced.

A quadrupole is present immediately prior to the screens in both transfer lines. It is thus important to note that the beta functions at the two screens are tuned to approximately the same value (within a factor 2) so that their effect is negligible and does not influence the beam size on the screens. To verify that the increased in energy spread on the second screen actually only depends on the longitudinal wakefields and not on the optics, the wakes can be occasionally switched off in the simulation. The resulting energy spread at the screen 2 should then look similar to the one on screen 1.

RESULTS AND DISCUSSION

Since the wakefields are directly proportional to the charge and thus also the compression of the bunch we performed simulations for two different compressions, varying the total charge of the beam between 100, 250 and 500 pC. In case A, the beam is compressed to 0.1 ps (rms) which corresponds to the compression used in the regular SPF mode of the machine, i.e. a fully compressed beam. In case B, a much milder compressed beam of 1.0 ps (rms) is used. Depending on the compression the relative energy spread on the screens alters strongly. To capture the whole beam on the screens the phase in the linac section 1 is adjusted differently for case A and B.

The growth of the relative energy spread (in %) due to the longitudinal wakefields on the second screen compared to the screen 1, for the different configurations, is found in table 1. The effects from the longitudinal wakefields are, as expected, most visible for the 500 pC beam in case A, due to the stronger compression and high charge, see Fig. 3. Here, the energy spread at screen 2 has increased about 43% compared to the spread on screen 1. The difference in energy spread is thus easily seen on the screens and it is directly proportional to the difference in longitudinal phase space in Fig. 2.

Notice that the projected energy distribution is the same at screen 1 as for the longitudinal phase space before the transfer line 1, as well as, the projected distribution is the same at screen 2 as for the longitudinal phase space before the transfer line 2. This proves that the beam on the screens really corresponds to a projection of the longitudinal phace space before the transfer lines. The over all shape at the two screens, Fig. 3 is similar although we can see more microbunching of the particles at the second screen. This is a numerical microbunching resulting from too few particles (100 000) used in the simulations.

In future SPF mode operation of the machine the total charge of the beam is not intended to exceed 100 pC, but according to these simulations the increase in energy spread due to the wakes should still be detectable for lower beam charge, e.g., a growth in energy spread of 12.5% and 6.1%

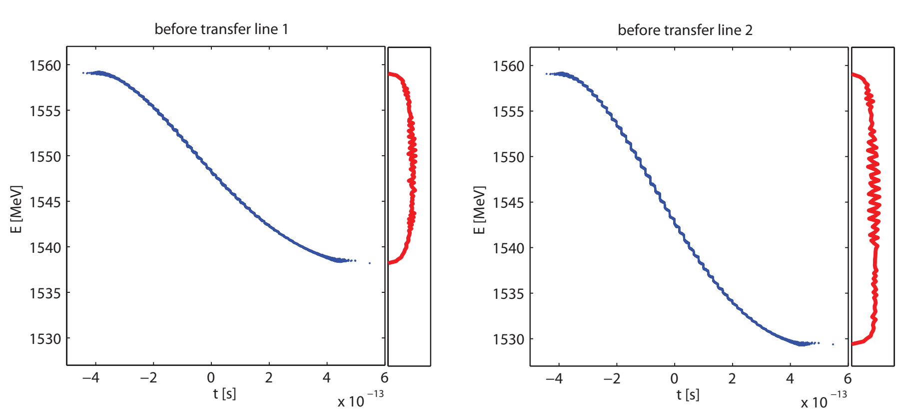

Figure 2: Simulations of longitudinal phase space prior to transfer line 1 (left) and transfer line 2 (right). The beam have a charge of 500 pC and is strongly compressed (later defined as case A). The projected energy distribution is represented in red.

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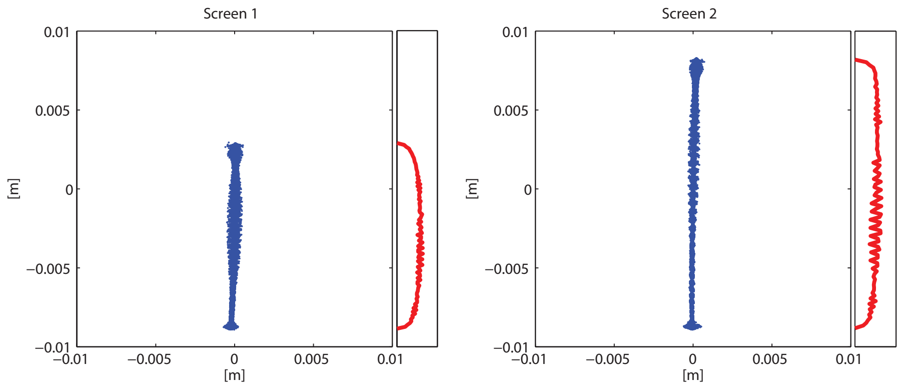

Figure 3: Simulations of electron beam at the screen 1 in transfer line 1 (left) and screen 2 in transfer line 2 (rigth) for the 500 pC beam in case A. The projected energy distribution is represented in red.

for case A and B respectively is predicted for the 100 pC beam.

This method can also be used to deduce at which charge and compression the effect of the wakefields can be considered as negligible. For both compression cases A and B, the effect from the wakefields become weak when the total charge of the beam is reduced to 10 pC. At this low charge the growth of the energy spread at screen 2 is 1.6% for the strongly compressed beam. This will be a way to tune the dispersion in the transfer lines in the real machine. The projected energy spread on the screen is of course sensitive to the change in dispersion but is very weakly influenced by the beta function. For instance, beta value of 7 m at screen 2, influences the beam size only by 1 μm which is not detectable with on the screen.

Table 1: Total energy spread increase (in %) due to longitudinal wakefields in linac section 2 for different charges and compressions

Charge (pC)	Case A	Case B
500	43.2	26.9
250	26.5	14.9
100	12.5	6.1
10	1.6	0.1

CONCLUSION AND OUTLOOK

Using the method presented in this paper, the longitudinal wakefields in the MAX IV linac structures can be characterized. The wakes' direct influence on the energy chirp of the beam can hereby be deduced which is an important step since minor variations in energy chirp strongly affects the compression achieved in BC2 and subsequently the peak current delivered to the SPF. Furthermore, with this technique the beam sizes on the screens are almost not influenced by beta value variation, which makes the method reliable.

Applying the proposed method to the real machine is rather simple and do not require any extra equipment than what is already planned in the two transfer lines. Nevertheless, it gives us enough information to identify the effect from the wakes and, together with the predictions presented in these proceedings, a way to verify the longitudinal wakefield model used in our simulations.

When running the machine at a very low beam charge (10 pC) the simulations show that the effect of the longitudinal wakefields can be considered negligible. Thus, the beam observed on the two YAG screens should in theory look identical which gives us a way to adjust the dispersion in the transfer lines.

The longitudinal wakes also introduce nonlinearities in the longitudinal phase space which are not directly visible on the screens. Therefore it is of interest to continue investigating the energy chirp distribution more carefully. By shifting the phase in the first linac section it should be possible to reconstruct the approximate phase space of the beam once the effect from the longitudinal wakefields known. At present, the numerical microbunching is a problem and more particles in the simulations are necessary to overcome this. This is ongoing work.

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