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CREATING TWO-PULSE BEAMS FROM A PHOTOINJECTOR FOR TWO COLOR FEL OR BEAM DRIVEN PWFA EXPERIMENTS

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Abstract

The MAX IV linac is investigated as a FEL driver in the SXL project, but there is also an ongoing investigation in using the linac as a driver for beam driven plasma wakefield acceleration experiments. From both these applications, double pulses from the photoinjector within the same RF period is desired. In this paper we discuss the possibilities of using the current photoinjector at MAX IV as driver and show simulations results from the pre-injector, both for FEL applications and for PWFA applications.

INTRODUCTION

The MAX IV linac [1] is a normal conducting warm S-band linac with a final energy of 3 GeV. The linac is the injector for the two storage rings at MAX IV, and also produces short electron beams for the short pulse facility [2]. Recently a project started to design a Soft X-ray free-electron Laser (the SXL project [3]) using the photo-cathode electron beam from the MAX IV linac. A possible feature for the SXL is the ability to produce two color FEL radiation, as has been implemented at several other labs and has also been investigated for the MAX IV linac [4]. There is also an ongoing project at the Department of Physics at Lund University to use the electron beam from the MAX IV linac for beam driven plasma wakefield acceleration experiments [5]. One way to realize both these scenarios could be to use two temporally separated electron bunches within the same RF period. The detailed specifications for the bunches in the different schemes are not known at this time, but some general properties can nevertheless be assumed. For the plasma driven beam acceleration using the driver-witness configuration, it can be beneficial to have the driver bunch containing more charge than the witness bunch to more efficiently drive the plasma wakefield bubble. In this scheme the witness bunch should have an emittance lower than 0.4 mm mrad, but for the driver bunch the requirements are a bit more relaxed. For the two-color FEL case two bunches with roughly the same charge has been the scope, and the beam should have an emittance around 0.4 mm mrad, or lower. In this paper the current pre-injector (photo-cathode gun, solenoid and first linac structure) at MAX IV is first described. Then it is investigated through simulations in ASTRA [6] if it is possible to produce these double bunch structures with the current pre-injector, or what changes would otherwise be needed. The scope of the simulations is only the pre-injector, simulations for the rest of the linac with respect to the bunch compression and transport has partly been done in [5] and is partly work in progress.

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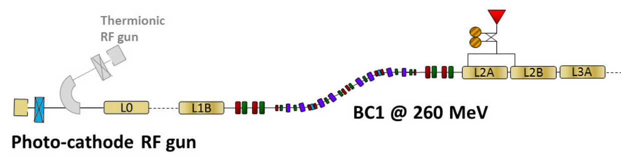

Figure 1: Overview of the MAX IV injector where the photo-cathode gun is to the lower left. It is followed by a solenoid and then the first linac structure (L0). BC1 is the first bunch compressor after 3 linac structures at an energy of 260 MeV, and is followed by the main linac.

PRE-INJECTOR DESIGN

Current Pre-Injector

The pre-injector for the MAX IV linac has two electron sources, one photo-cathode gun and one thermionic gun. A simple view of the pre-injector components and layout can be seen in Figure 1.The photoinjector line of the pre-injector is a BNL/SLAC 1.6 cell photo-cathode gun with a finely machined, but not polished, copper cathode. The gun is powered by a SLED amplified S-band pulse at 2.9985 GHz, the pulse length is approximately 0.7 μs, and the maximum electric field in the gun is approximately 100 MV/m. The current gun has been commissioned to approximately 110 MV/m but during operation 100 MV/m is usually used. There is an ongoing project within the SXL project to produce a new photo-cathode gun capable of higher electric field amplitudes [7]. A Radiabeam solenoid is used for emittance compensation and is mounted as close to the gun as mechanically possible, however the field from the solenoid does not extend to the cathode so no bucking coil is installed. The laser beam is injected with a small angle to the beam propagation axis and all optical components are outside the vacuum chambers. The entrance to the first linac structure is at 1.5 m from the cathode, and the structure is a 5.2 m traveling wave accelerating the electrons to 100 MeV.

Double Laser Pulses

The laser pulses are generated in a commercial Ti:Sapphire system. They are frequency-tripled to produce up to 500 μJ of ultraviolet at 262 nm, with a bandwidth of about 1.6 nm and a near transform-limited pulse duration. The pulses are stretched to a picosecond duration using a prism strecher. A Mach-Zendher interferometer will be used to generate the double pulses. In order to control the relative spatial spot size of the beams in the different arms of the intereferometer, the plan is to use either hard clipping on apertures, or a down-collimating telescope in one of

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the arms, or a combination of both. Non-polarizing beam-splitter at the input of the interferometer is also planned, and a polarizing cube beam-splitter as a combining element. A half-wave plate-polarizer combination in one of the interferometer arms is to be used to set the relative energy of the two pulses, in addition to their total energy being controlled at the laser output. Since the two pulses exit the interferometer linearly polarized and with orthogonal polarization, it is possible to use one or more birefringent crystals to stack each of the pulses individually before they are directed towards the cathode.

NUMERICAL SIMULATIONS

To simulate the pre-injector ASTRA and parallelized ASTRA [8] were used. Due to the large number of particles, parallelized ASTRA was mainly used at LUNARC (The center for scientific and technical computing at Lund University) to be able to simulate different combinations of parameters more efficiently. The setup is simulated using a large number of particles (700k), and the number of grid points are extended in the longituindal direction to 80 to properly capture the longitudinal behavior of the bunches. The beam is assumed to be radially symmetric, and in the simulations an intrinsic emittance of 0.55 mm mrad/mm was used. Initial simulations were done with the aim to find basic beam parameters and a basic operating point for the gun. The results from these simulations indicate that for a spot size of approximately 1 mm diameter, an individual bunch length of 2.4 ps and 4.6 ps separation between the bunches gives a good double bunch structure out from the gun when operating at 35 degrees off crest at an maximum field of 120 MV/m. As expected the two individual bunches merge if the field in the gun is too low at time of laser injection, or if the two bunches are temporally too close together, in combination with too high charge density. One of the aims in these simulations has been to keep the two bunches completely separated, while still keeping the total beam length as short as possible.

To be able to transport and compress the beam efficiently, the idea is to keep both bunches similar with respect to emittance and optics. In the simulation process it showed most successful to view the two bunches as one beam, and aim to control the properties of the full beam while making small changes to the individual bunches. It was tested to have completely different spot sizes and longitudinal properties for the two bunches, which did not improve the results. One of the factors that affect the possible bunch configurations is the field in the linac, 20 MV/m in a travelling wave structure, setting the conditions for proper matching. Both bunches have the same length after the laser split, and the separation was in these experiments kept as small as possible.

Driver-witness beam Driven Plasma Acceleration

For the driver-witness experiment beam it was found through iterative simulations that a charge of 120 pC in the driver bunch and 80 pC in the witness bunch gave reasonably good beam quality. For 2.4 ps long bunches with 1

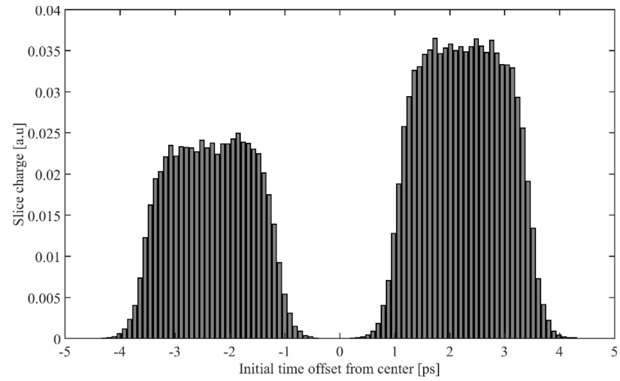

Figure 2: Initial longitudinal bunch distribution for the driver-witness acceleration.

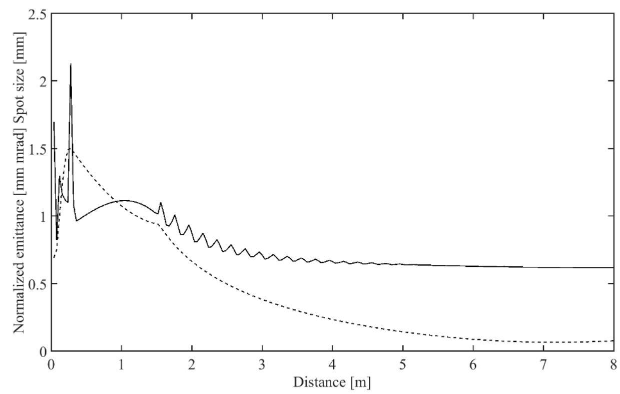

Figure 3: Evolution of the projected emittance for the full beam (solid) and for the spot size (dashed).

ps rise-fall time, 1 mm spot size and 4.6 ps separation (the initial longitudinal distribution can be seen in Fig. 2), the transverse emittance and spot size evolution up until the end of the first linac are shown in Fig. 3. The final energy is 100 MeV with an energy spread of 150 keV for the full beam. Figure 4 shows the slice emittance for the driver and witness as well as the current distribution at the end of the first linac. The emittance is 0.6 mm mrad for the driver and 0.4 mm mrad for the witness bunch respectively. As can be seen in the figures the beam is not injected into the linac at the proper emittance compensation point, however the working point in these simulations turned out to have an acceptable emittance at the same time as transportable optics.

Two Color FEL

For the two color mode simulations, a charge of 50 pC in each bunch was used together with the same longitudinal and transverse parameters as beam driven experiment bunch (2.4 ps long, 1 ps rise/fall, 1 mm spot size, similar to Fig. 2 but with equal charge in both bunches). The separation was set to 4.6 ps and the resulting transverse emittance and spot size evolution up until the end of the first linac is given in Fig. 5. The emittance for the head bunch is 0.39 mm mrad and for the tail bunch 0.36 mm mrad and the final energy is 104 MeV with a beam energy spread of 120 keV. Figure

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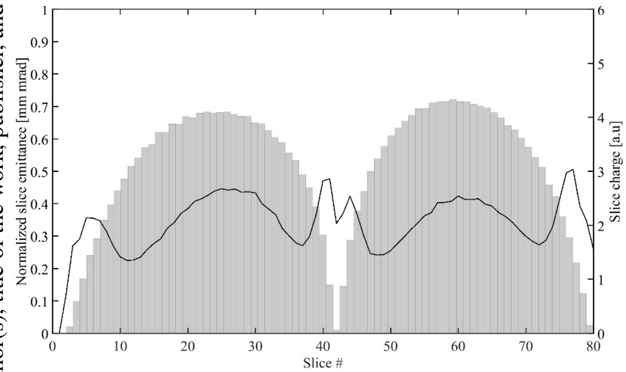

Figure 4: Slice emittance and charge distribution for the driver-witness beam at the end of the first linac (approximately 7 m).

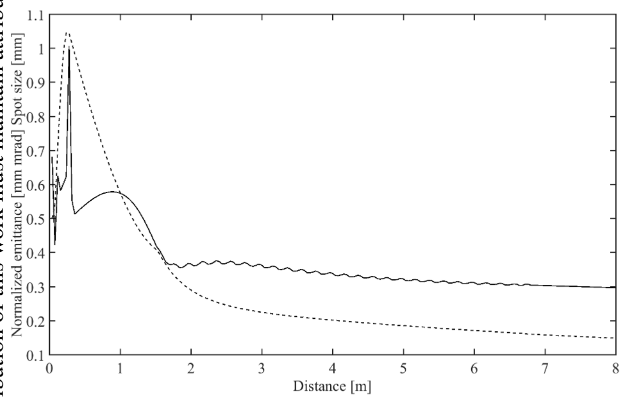

Figure 5: Evolution of the projected emittance for the full two beam (solid) and for the spot size (dashed).

6 shows the slice emittance for the bunches as well as the current distribution at the end of the first linac.

CONCLUSIONS

The simulations show that in order to accelerate and keep two bunches with relevant charge levels at reasonable quality, a field of 120 MV/m or higher is needed in the gun. This indicates that it will be challenging to use the current photo-

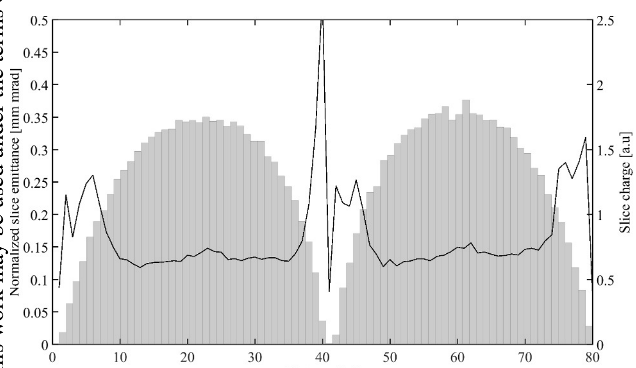

Figure 6: Slice emittance and charge distribution of the two color beam at the end of the first linac (approximately 7 m).

cathode gun in operations, since it would need substantial conditioning to reach these field amplitudes. Preliminary simulations shows that it would be possible to create and transport a beam with a lot less charge in the current gun, however at charge levels that mainly could be interesting for two color FEL experiments. However, a new photo-cathode gun under development with an expected maximum electric field amplitude higher than 120 MV/m, and within a year this gun should be available.

The simulations shows that it will be possible to produce electron bunches for the two different applications. For the two color mode the emittance is kept under 0.4 mm mrad for both bunches with 50 pC charge in each bunch, and for the driver-witness beam with 120 pC in the driver and 80 pC in the witness, the driver can be kept under 0.6 mm mrad and the witness under 0.5 mm mrad. The next step in the process will be to test double pulse generation in the gun test facility at MAX IV to investigate if two cleanly separated bunches can be generated in the new photo-cathode gun. At the same time work is progressing on defining the exact bunch structures for the experiments, as well as proceeding with simulations for the beam in the bunch compressor and linac.

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