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THE PRE-INJECTOR AND PHOTOCATHODE GUN DESIGN FOR THE MAX IV SXL

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Abstract

The design of the pre-injector, including the new gun, for the SXL project [1] is being finalised for the desired modes of operation, 100 pC and 10 pC with short bunches. The photocathode gun is currently being manufactured and experiments in the MAX IV guntest facility are under preparation to verify the design. In this paper we present the design of the gun and the pre-injector and show some results from simulations using MOGA indicating an emittance less than 0.3 mm mrad.

INTRODUCTION

The MAX IV SXL project is currently in a conceptual design phase, with the goal of investigating the design of a Soft X-Ray Laser source at the end of the MAX IV linac in Lund, Sweden. The MAX IV linac is a normal conducting S-band linac accelerating electrons to a final energy of 3 GeV, and the current electron source for photocathode operation is a 1.6 cell S-band gun with a copper cathode. The pre-injector is here considered to be the photocathode gun, the emittance compensating solenoid and the first linac structure, as well as relevant diagnostics. The layout of the current pre-injector, as well as the first bunch compressor and beginning of the main linac, can be seen in Fig. 1. The pre-injector should be operated in, or close to, the well known emittance compensation regime [2].

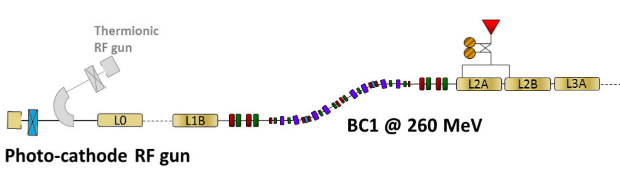

Figure 1: Overview of the MAX IV pre-injector and first bunch compressor. The photocathode gun is on the lower left and beam propagates to the right. The beamline coming from the top is the thermionic pre-injector.

PRE-INJECTOR DESIGN

The photocathode gun currently in operation is a 1.6 cell S-Band gun with symmetric coupling and pumping ports on the full cell. The gun has been in operation since 2014 with a beam quality of approximately 2 mm mrad for 100 pC, at fields amplitude of approximately 90 MV/m. The repetition rate is currently 2 Hz, and will in the near future be increased to 10 Hz, whereas the final repetition rate should be 100 Hz. The current installed gun will not be able to operate at 100 Hz due to limited cooling. The RF gun shares klystron with the first linac structure, and is powered by a SLED amplified RF pulse. The RF power goes through an attenuation/phase shift system in order to control these parameters independently of the first linac. The gun is followed by an emittance compensation solenoid, which is placed as close to the gun as mechanically possible. The distance between the cathode and the entrance to the first linac structure is 1.5 m which is possible to change, however it requires significant mechanical reconstruction. Following the solenoid is a laser chamber that allows the laser beam to be sent in at an angle close to on axis, this chamber also contains a pepperpot and a YAG screen for diagnostics. The laser system is a commercial Ti:sapphire system at 263 nm. At 1.5 m the beam enters the first linac structure, a 5.2 m long S-band linac, and is accelerated to approximately 100 MeV.

Photocathode Gun

A new gun with improved cooling and improved RF parameters is required for 100 Hz operation. The new gun design is a 1.6 cell S-Band structure at 2.9985 GHz, incorporating improvements compared to the current gun such as elliptical irises, racetrack profile and z-coupling. The design has two symmetric z coupling slots but initially power will only be fed through one of them in order to simplify the replacement of the current gun. The symmetric z-coupling slots combined with a race-track profile, as discussed in [3], is designed to minimize the quadrupole components of the field. The diameters of the iris and cells has been modify to increase the mode separation, thus minimizing the excitation of the 0 mode field. For the gun currently in operation some mode beating is observed, likely caused by the short RF pulse in combination with the small mode separation of 16 MHz. In the new design the mode separation is 40.5 MHz and this should mitigate the mode beating. Some parameters

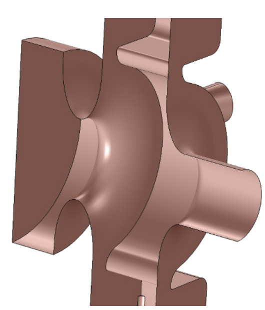

Figure 2: Cut-through picture of the new mechanical gun design.

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for the gun are summarized in Table 1, and a cut through of the gun can be seen in Fig. 2.

Table 1: RF Parameters from Simulations

Parameter	Value
f_0	2.9985 GHz
E_{cath}	120 MV/m
Q_0	14050
β	2.24
$0-\pi_{sep}$	40.6 MHz
E_{surf}/E_{cath}	0.9
$T_{nominal}$	38
RF pulse length	$0.8\mu s$
Cathode	Copper

The cooling of the gun structure uses water, and the design is for a maximum repetition rate of 100 Hz at 140 MV/m. The radius of the z-coupling, laser ports and rf probe ports have all been designed in order to keep the pulsed heating temperature increase below 60 °C, even for the high input power contained in a SLED pulse. There is also a separate fluid circuit designed on the back of the cathode that can be used both for cooling and for heating up the cathode in-situ.

The structure is being manufactured in house using high grade low oxygen copper, and the different parts will be joined using brazing. It was investigated to manufacture it with a form of heat joining, but the initial experience with this technique indicated issues with vacuum performance, and thus brazing was chosen.

RF and Linac

The gun is be powered by a klystron and SLED that is shared with the first linac structure. The first linac is a constant gradient travelling wave structure, 5.2 m long, manufactured by Research Instruments. The output from the SLED is a short pulse with a high initial power, and the coupling of the gun have been designed in order to benefit from the short pulse with high energy.

The SLED amplification in combination with a constant gradient linac structure gives an electric field that is increasing along the length of structure. The first linac is a central part of the emittance compensation process, and it is currently being investigated if the envelope of this accelerating gradient has any effects on the emittance compensation process. Preliminary results from simulations indicates that the matching properties are mainly dependent on the amplitude of the accelerating field at the entrance of the linac when the beam arrives, as expected. Compared to a constant gradient travelling wave linac, with the same amplitude, it seems that the beam quality is the same, but this is to be further investigated through experiments.

Cathode

The cathode material is copper, and the cathode is the back plate of the gun structure. There are ongoing experiments to determine the best preparation of the cathode surface in order to get good beam quality and a high initial QE. Currently, the preparation "recipe" for the cathode is machining in house, followed by diamond polishing by an external company. The cathode is then cleaned in the MAX IV vacuum lab, after the protective coating has been removed. Following cleaning the cathode is mounted in a transport chamber, and the cathode is baked in this chamber at 250° C for 72 hours while the chamber is continuously pumped. After baking the chamber is filled with nitrogen and kept sealed until the cathode is to be mounted.

The mounting of the cathode currently requires the disassembly of the back end of the gun, a procedure that can be done in approximately 30 minutes time. So far a load-lock mechanism has not been implemented but has been discussed, there is ample space behind the gun for such a system, and the idea would be to replace the cathode with a cathode adapted for a load-lock system.

Laser

The laser system used in the pre-injector is a commercial Ti:sapphire system produced by KM labs. The laser oscillator is mode locked to the RF of the gun to ensure proper phase synchronization. The pulse is frequency tripled to 263 nm, the beam shape can be controlled by a pulse shaper (both longitudinally and transversely) and pulse stacking can also be used to create the desired pulse shapes. The beam is transported into the linac, which is approximately 15 m away, through a vacuum tube and relay imaging is used to image an iris after the crystal onto the cathode.

Diagnostics

For beam diagnostics there is a scintillating YAG screen in the laser chamber, approximately 70 cm from the cathode, which can be used for intrinsic emittance measurement, alignment and beam shape diagnostics. A second YAG screen just in front of the entrance to the first linac in used in order to check the focusing at this point. In the laser chamber there is a pepperpot installed, but it is at the moment not usable due to the dimensions of the mesh. Currently there is no energy diagnostics in the pre-injector, but it is being investigated if the energy filter, that is a part of the thermionic pre-injector, could be used for this purpose.

Intrinsic emittance is measured using the solenoid and first screen at lowest detectable charge on the screen (<3 pC). Initial measurements indicates an intrinsic emittance for the current cathode of $0.9\mu mrad/mm\sigma_z$ at 90 MV/m accelerating gradient and 30 degrees phase. Projected emittance measurements are made using single quad scan method after three linac structures, at a beam energy of 275 MeV. There is ongoing work on implementing multi-quad emittance measurement methods, as well as implementing single solenoid scan after the first linac. Finally a slice

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emittance measurement method has been implemented in the dispersion section in the first bunch compressor, using the second linac at an off-crest phase, where slice emittance can be measured at a resolution of approximately 0.4 ps [4].

BEAM DYNAMICS

To investigate the beam dynamics in the pre-injector ASTRA is used. The field in the gun is an axial symmetric field map for most simulations, but some simulations are also done with a full 3D map extracted from the field modeling program to verify the accuracy of the symmetric approximation. The solenoid field is taken from measurement, and the linac has field map based on the SLED envelope. ASTRA is used with the framework DEAP (distributed evolutionary algorithms in python) to do multi-objective optimization, MOGA to do multi objective optimization. For this purpose a wrapper has been written to adapt to ASTRA simulations, where several nobs and performance figures can be used. Finally Impact-T is used to compare and verify the ASTRA results, there is also ongoing work on implementing more parts of the injector into Impact-T.

There are two sets of simulations, one with the linac entrance at 1.5 meter (as the current mechanical setup), and one looking at possible difference in this distance. Initial results from the optimization indicates that there are no significant improvement from changing the position of the cathode, similar beam qualities can be produced at the current position which is not unexpected, since the current distance of 1.5 m is based on simulations for a photocathode pre-injector at the time of design of the MAX IV linac.

At 1.5 m distance, there are two modes of operation that are being investigated, one with 100 pC and one low charge at 10 pC. Since there is a direct correlation between the spot size on the cathode and the intrinsic emittance, the beam size should be as small as possible. The minimum spot sizes with acceptable field with respect to the space charge limit was set to cut-gaussian with sigma 0.25 mm diameter for 100 pC case, and 0.13 mm for the 10 pC case. The intrinsic emittance used in the simulations is 0.7 $\mu mrad/mm\sigma_z$, the transverse profile is a cut-gaussian with full width as stated previously and the temporal shape is a tophat, 6 ps long with 0.5 ps flanks. Table 2 shows the different configurations, their initial emittance, projected final emittance, energy spread and bunch length. As can be seen the bunch length of the 10 pC is shorter than for the 100 pC case as expected, even though the same initial pulse length is used. In Fig. 3 the spot size and emittance evolution can be seen for two of the cases. 10 pC at 1 mm shows very little features other than beam size focusing so for clarity this case is not in the figure. Preliminary results also indicates that it is possible to maintain a sub 0.3 mm mrad emittance for a much shorter initial pulse length as well in the 10 pC case in case a short pulse is needed.

Table 2: Simulation models, for 6 ps long top hat pulse with 0.5 ps rise/fall edges. Intrinsic emittance 0.7 mm mrad/mm. Sizes in mm and emittances in mm mrad. Final energy 100 MeV.

Q [pC]	σ_r	ε_{cath}	$\varepsilon_{proj,100\%}$	σ_z	dE (%)
10	0.13	0.09	0.1	0.4	0.04
10	0.25	0.18	0.2	0.38	0.04
100	0.25	0.18	0.24	0.49	0.06

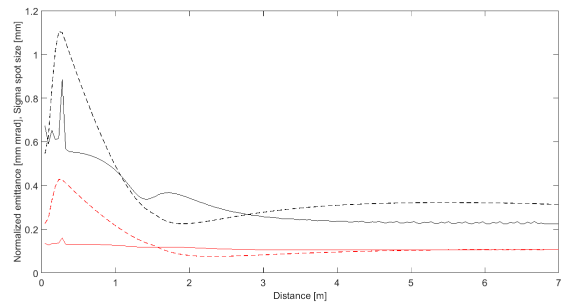

Figure 3: Beam envelope (dashed) and emittance evolution for 100 pC (black) at σ_r = 0.25 mm and for 10pC (red) at σ_r = 0.13 mm.

SUMMARY

In this paper we have presented the current status of the design of the photocathode gun and the pre-injector for the SXL project at MAX IV. The new design for the photocathode gun with z-coupling, elliptical profile, larger iris and improved cooling will be able to operate at 100 Hz at maximum field amplitudes of 120-140 MV/m. Beam dynamics are investigated, and the simulated projected emittance is found to be lower than 0.25 mm mrad for the current investigated modes of 100 pC and 10 pC charge.

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