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THE PRE-INJECTOR DESIGN FOR THE MAX IV SXL

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Abstract

In this paper we present the current status of the design for the pre-injector (photo-cathode gun, solenoid and first linac) for the SXL [1] project at MAX IV. The SXL project requires a higher repetition rate and since improved beam quality compared to what the current photo-cathode gun can operate at is needed, a new photo-cathode gun will be manufactured. We briefly describe the components of the pre-injector, followed by the design of the new photo-cathode gun. The design is similar to the old gun but with a new RF cavity using elliptical irises and racetrack profile main cell. The current parameters for the next gun to be manufactured are discussed, and some simulations and expected beam quality from the injector are shown.

INTRODUCTION

The MAX IV SXL project is currently ongoing with the goal of investigating and designing 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, with two different electron sources. One thermionic RF gun used for injection to storage rings, and one photo-cathode RF gun for production of beams for the Short Pulse Facility (SPF) [2]. The currently installed photo-cathode gun is a 1.6 cell gun based on the BNL/SLAC type adapted for 2.9985 GHz, and results from the initial commissioning can be found in [3], where a beam emittance in the order of 1.6 mm mrad was measured. The available repetition rate with the currently installed gun is too low for full operations of the SPF. At the same time, the beam quality needs to be improved to efficiently drive a FEL and in combination, this requires a new photo-cathode gun and a revisit of the design of the pre-injector.

The pre-injector is considered to be the photo-cathode gun, emittance compensating solenoid and first linac structure as well as all connected diagnostics. In the current pre-injector design the gun is followed by a Radiabeam solenoid used for emittance compensation, and a layout of the current pre-injector can be seen in Fig. 1. The pre-injector should be operated in, or close to, the well known emittance compensation mode [4].

NEW GUN DESIGN

Several options for a new design of the electron source have been considered, for example DC guns or RF guns at different bands than S-band. Since other RF systems in the linac are S-band, introducing a new band has not been considered an appealing path at current point in time. One of the goals with the new gun version is therefor to be able to

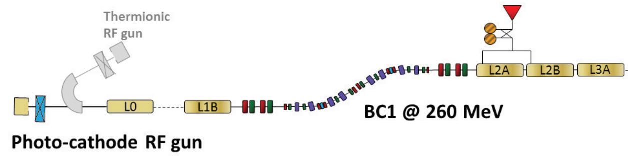

Figure 1: Overview of the MAX IV pre-injector. The photo-cathode gun is on the lower left and the beam propagates to the right. The beamline coming from the top is the thermionic pre-injector.

install it as a "swap" with the current gun, i.e. the dimensions and construction should be kept as close as possible to the current gun to minimize the amount of mechanical work needed in the pre-injector area to replace the current gun.

CURRENT DESIGN

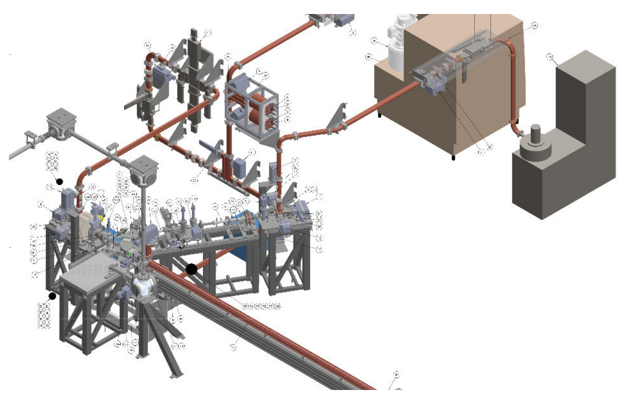

Figure 2: The MAX IV pre-injector and RF system overview. The photo-cathode gun is to the lower left marked 43, followed by the emittance compensating solenoid, diagnostic section and first linac.

The photo-cathode gun at 2.9985 GHz has a mode separation is about 16 MHz. The current gun has a single power feed with compensating ports in the full cell, and two laser ports in the cathode cell. It was manufactured in-house from high grade oxygen free copper, and the brazing, RF characterization and initial commissioning were also carried out in-house. The cathode is a finely machined but not polished copper cathode. The RF gun shares klystron with the first linac structure, and is powered by a SLED amplified RF pulse. The pulse length is approximately 0.7 μs during operations. The RF power to the gun goes through an attenuation/phase shifter system to be able to change phase and power going into the gun independently of the operation for the first linac structure. The current pre-injector,

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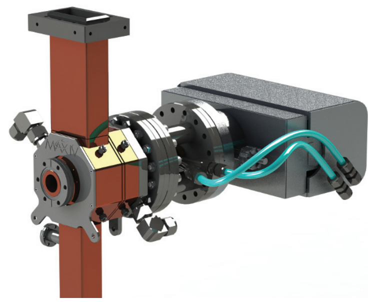

Figure 3: The exterior of the new gun design with attached vacuum pumps.

including the RF systems, can be seen in Fig. 2. The gun is followed by an emittance compensation solenoid which is placed as close to the gun as mechanically possible, and the distance between the cathode and the entrance to the first linac structure is 1.5 m. There is room to change this distance if needed but it requires major mechanical reconstruction. The solenoid contains PCB's for normal and skew quadrupole field compensation, but these have not yet been implemented. Following the solenoid is a laser chamber that allows the laser beam to be sent in close to on axis towards the cathode, and this chamber also contains a pepperpot and a YAG screen for diagnostics.

As can be seen from the figures, the photo-cathode pre-injector intersects with the thermionic pre-injector used for ring injections. There is an energy filter and two quadrupole magnets that are used during injections with the thermionic electron source, and so far there has been no significant indications that hysteresis causes issues with the photoinjector beam. During commissioning and subsequent experiments it has been possible to reach a beam quality of just below 1 mm mrad with a charge of 100 pC [5]. Since the cathode is non-polished it is believed that this is a substantial contribution to the emittance, and normal operating emittance with around 2 mm diameter laser spot size is typically 2 mm mrad for 100 pC charge.

Based on the requirements for the repetition rate and beam quality, combined with the progress on photo-cathode RF gun designs, a new design for the photo-cathode gun is being developed. There will be no significantly new features in the design that has not already been implemented in other gun designs, it is rather a combination of the most attractive features for the requirements at MAX IV. The design has been based on a 1.6 cell structure similar to the well known one from BNL/SLAC type guns. A 2.6 cell structure has also been considered, but is at the current time not investigated further.

The gun will feature elliptical irises to decrease the surface electrical field, thus making it possible to go to higher gradients while minimizing RF breakdowns. The design will use a one sided power feed through an z coupling slot on the main cavity to be able to easily connect it to current systems. There will be a symmetric z coupling slot at the other side of the cavity, and in combination with a race-track profile as discussed in [6], it should be possible to keep the multipole components at an acceptable limit. The exterior of the new gun can be seen in Fig. 3 and the RF cavity as simulated in SUPERFISH [7] can be seen in Fig. 4.

The dimensions of the irises have been changed to increase the mode separation between the pi and 0 mode, while keeping the field amplitudes equal in the two cells. In the currently installed gun some mode beating is seen, the effect of it is being studied, but the mode separation is increased to 40 MHz in the new design to be able to power the structure with short pulses from the SLED without significant zero-mode excitation.

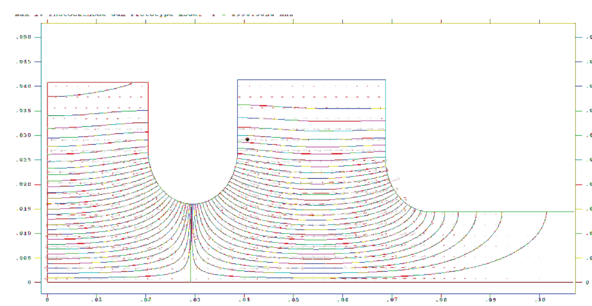

Figure 4: Simulation results showing electric field contour lines and direction from Superfish for the new RF gun cavity design.

The cooling system using water is being designed for operations at 100 Hz with a maximum field amplitude of 130 MV/m, and heat load is being simulated with COMSOL and ANSYS. The projected field amplitude during operations will however be lower, in the range of 110 - 120 MV/m. There is also a fluid circuit designed on the back of the cathode both for cooling but possibly also to be able to heat up the cathode in-situ.

The structure will be manufactured in high grade low oxygen copper and will be manufactured in house. The current technique to combine the structure is a "heat joint", where temperature expansion will be used. In the initial trials with this technique it has been able to keep the temperature far from the point where the mechanical structure of copper changes. Previous experience elsewhere seems to indicate that conditioning is faster and less breakdowns occur if the structure has not been heated to high temperatures. As we are trying to keep avoid brazing for this reason, the alternative idea is to implement a clamping process as in [8]. However, the mechanical design is done in such a way that brazing is possible even after joining if required. RF measurements will be made both with the bead and needle pull technique to measure the electric field distributions in the structure.

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BEAM SIMULATIONS

The electric field profile in the new design of the gun will have equal amplitudes in the two cells, and the field profile is very similar o the one in the current gun. There are no major changes to the simple beam dynamics expected and the pre-injector will be operated as close to the emittance compensating work point as possible. Simulations are made using ASTRA [9] and parallelized ASTRA [10] using the resources at LUNARC (The center for scientific and technical computing at Lund University). 1 M particles and a radially symmetric space charge grid where used, and the intrinsic emittance is estimated to 0.55 mm mrad/mm. In the pre-injector designs a 1 mm diameter laser beam is used, the intrinsic emittance is 0.17 mm mrad, and the laser beam is longitudinal top hat like with a length of 6 ps with around 1 ps rise/fall time. The field in the gun is 120 MV/m, the laser is injected at a phase of 35 degrees and the beam charge is 100 pC. Figure 5 shows the spot size and emittance evolution and Fig. 6 shows the charge distribution and the slice emittance. The final emittance is 0.23 mm mrad, at a beam energy of 104 MeV and 60 keV energy spread. The current working point is not perfect with respect to emittance compensation (the Ferrario working point). As can be seen from Fig. 5 the beam enters the linac (at 1.5 m) just after the first emittance oscillation minimum instead of the following maximum, however operating the injector with the current settings give better emittance than operating closer to the Ferrario working point. Further investigations are ongoing to fully understand the causes for this, and to possibly improve the emittance further.

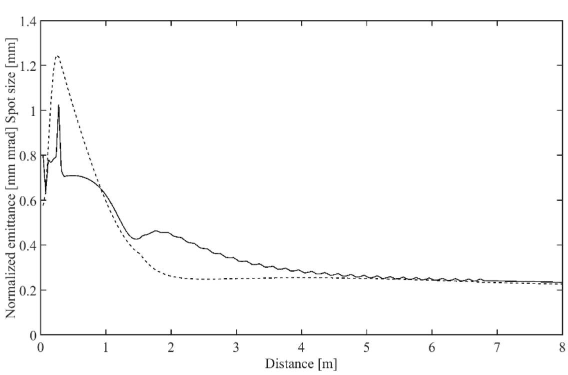

Figure 5: ASTRA simulation results showing the emittance (solid) and spot size (dashed) evolution up until the end of the first linac.

SUMMARY AND FUTURE

In this paper we have shortly presented the current status of the design for a new photo-cathode gun and pre-injector at MAX IV. The ideas for the new gun design were discussed, and some basic simulation results with expected beam quality from the pre-injector were shown. The gun design is currently ongoing and should be finalized during Q2 2018 and manufacturing of the structure should start during the autumn of 2018. Once the gun is manufactured it will be

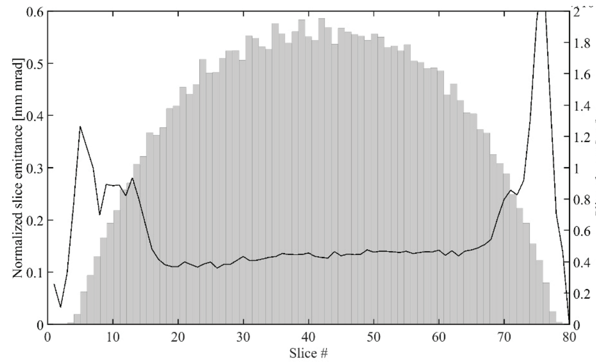

Figure 6: ASTRA simulation results showing the slice emittance and the charge distribution, the rms beam length is 0.5 mm.

commissioned and tested in the MAX IV gun test stand [11]. The new design will support stable operations at 100 Hz with at least a maximum field amplitude of 120 MV/m.

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