INITIAL COMMISSIONING RESULTS OF THE MAX IV INJECTOR

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Abstract

The MAX IV facility in Lund, Sweden is currently under commissioning. In the MAX IV injector there are two guns, one thermionic gun for storage ring injection and one photocathode gun for the Short Pulse Facility. The commissioning of the injector and the LINAC has been ongoing for the last year and ring commissioning is due to start shortly. In this paper we will present the results from beam performance experiments for the injector at the current stage of commissioning.

INTRODUCTION

The MAX IV facility [1] is under commissioning in Lund, Sweden. The facility has two storage rings for production of synchrotron radiation, one with 1.5 GeV and one with 3 GeV electrons. There is also a short pulse facility (SPF) [2] for the production of short pulses. The storage rings and the SPF are injected from a full energy LINAC. The injector for the LINAC has two electron guns, one thermionic gun [3] and one photocathode gun where the thermionic gun is used for ring injection. Due to the requirements of short bunches the thermionic gun is unsuitable for injection to the SPF and instead a 1.6 cell photocathode gun is used.

The commissioning of the injector and the LINAC started during the fall of 2014 and beam was commissioned until the recent shutdown period in May of 2015. During the commissioning all subsystems in the injector have been tested and brought online.

THE MAX IV INJECTOR

The injector system can be seen pictured in Figure 1. There are two parts of the injector, one leg where the thermionic gun is installed that injects into the main beam line through a 120 degree bend in an energy filter, and one straight leg for the photocathode gun.

Thermionic Gun Leg

The thermionic gun produces a beam from a BaO cathode using thermal heating. The beam is focused on an aperture using a solenoid, and between the solenoid and the aperture a chopper system [4] is shaping the beam into a suitable temporal structure for ring injection. For the initial ring commissioning scheme this will be three 3 GHz bunches within 10 ns (100 MHz) repetition time. The pulse length for each LINAC shot is 100 ns, where the pulse length is controlled using a stripline that is excited with a high-voltage pulse. The beam is refocused using a second solenoid, and then the beam proceeds into the first quad of the energy filter. The energy filter consist of four quadrupole magnets

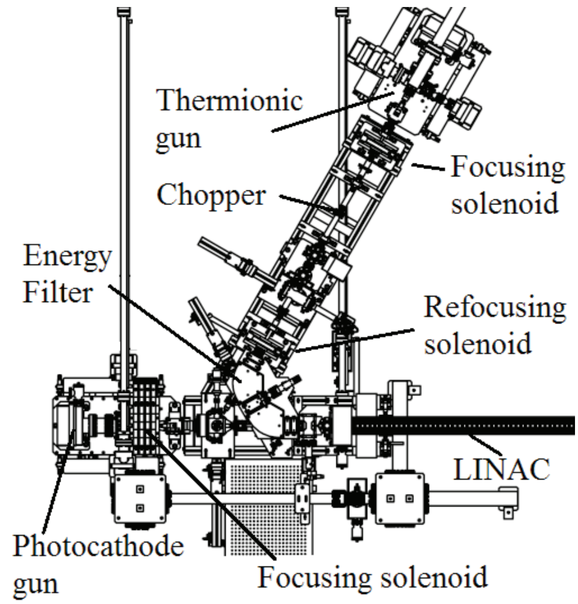

Figure 1: Blueprint of MAX IV pre-injector.

for focusing in the horizontal and vertical planes, two are located before the bending magnets and two located after. Between the two bending magnets there is a quadrupole magnet used to control the dispersion. There is also a scraper in the center of the energy filter, making it possible to adjust how much of the low energy tail of the beam that is accepted into the LINAC. The energy filter has a mechanical energy acceptance of about 200 keV and the beam is after the energy filter sent into the first structure of the LINAC. There exists multiple current transformers along the thermionic leg to measure the charge after the gun, before the energy filter and after the energyfilter.

Photocathode Gun Leg

The photocathode gun is operating at 2.9985 GHz and is based on the BNL/SLAC type for FERMI@Elettra [5]. The gun is powered by a 4 µs RF pulse via a SLED system. A laser with a wavelength of 263 nm is used to extract electrons from a copper cathode. The laser system is a KM Labs Dragon with cryogenic cooled Ti:Sapphire crystals. The laser has a oscillator at 76.9 MHz and its pulses are amplified, first in a regenerative amplifier and secondly in a multipass amplifier. Two kHz pump lasers are used to pump the amplifiers in the laser system. The pulse from the multipass amplifier is frequency tripled to a wavelength of 263 nm. The laser pulse is transported in an evacuated transport system from the laser room into the LINAC tunnel and is then focused on an iris where the beam size can be adjusted. The iris is imaged onto the cathode and the laser

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beam is coupled into the gun in the laser chamber close to on-axis. The solenoid is manufactured by Radiabeam and is installed close to the gun. For diagnostics there is a in flange fast current transformer from Bergoz directly following the solenoid, and in the laser chamber there is a YAG screen for imaging of the cathode. After the laser chamber the beam is sent into the first structure of the LINAC.

There are three LINAC structures following the injector and following the last structure there is a matching section where it is possible to do emittance measurements using the quad scan technique. The beam is then sent into the first bunch compressor and further on to the main line of the LINAC. The bunch compressor contains dipole magnets that are also used for energy measurements.

SIMULATIONS

Simulations have been done for both legs of the injector system. The simulations were made using Parmela [6] using a model of the electric field in the gun based on a 2D symmetric model in Supefish [7]. For validation the first meter of the thermionic leg has also been simulated in Astra [8] using a full 3D model of the thermionic gun produced in COMSOL Multiphysics [9]. No large discrepancies have been found between the two simulations. The thermionic injector should be able to produce a beam with at least 20 pC of acceptable charge per 3 GHz bucket, 2.3 MeV kinetic energy and an emittance below 10 mm mrad after the first LINAC structure. The simulations in Parmela show an emit-tance of 5.6 mm mrad after the first LINAC structure at 100 MeV. The beta functions along the injector can be seen in Figure 2, there is both a horizontal and vertical focus in the center of the energy filter at approximately 2.5 m from the cathode.

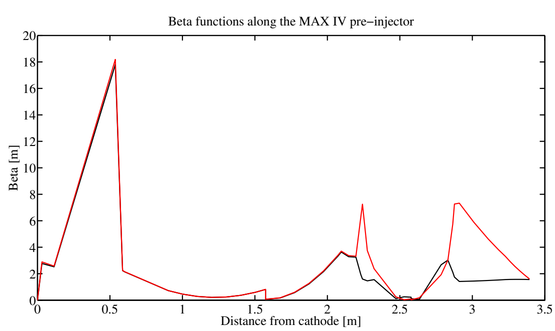

Figure 2: Simulated optics of the thermionic injector.

The photocathode beam simulations were made in ASTRA using a 3D gun field model from COMSOL, a transverse gaussian laser profile with a beam size of 1 mm and a longitudinal top hat profile with a length of 6 ps. The charge was set to be 100 pC . Using these parameters it is expected that the injector produces an electron beam with an emittance of 0.4 mm mrad at an energy of 100 MeV after the first LINAC structure. The energy spread is about 0.5 percent, and the simulated emittance and spot size evolution along the injector can be seen in Figure 3.

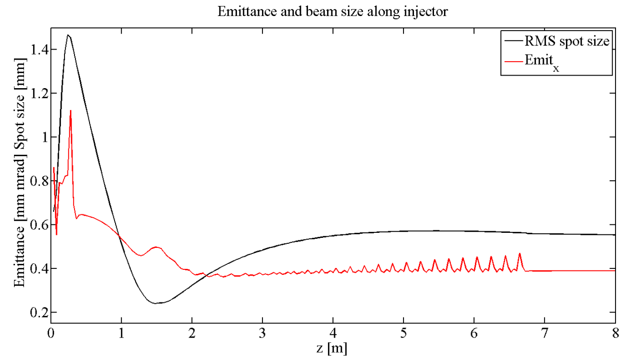

Figure 3: Emittance and beam envelope of the photocathode injector.

BEAM PERFORMANCE

Thermionic Gun

The thermionic gun has been conditioned during two different periods. The gun was first conditioned and basic measurements done in the MAX IV gun test stand [10]. The gun was then moved and installed at the MAX IV site where it was further conditioned. During the commissioning the gun performed well and very few RF breakdowns were experienced. The expected charge was delivered, and during commissioning it was possible to control the beam properties through the thermionic leg using solenoids and quadrupole magnets. A typical transverse beam going into the first LINAC can be seen in Figure 4, in this case for a 500 MHz bunch train structure, from a YAG crystal screen.

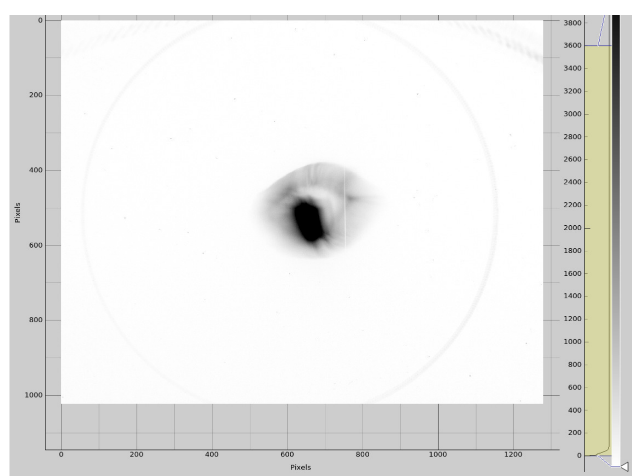

Figure 4: Thermionic beam on a YAG screen before first LINAC structure.

The aperture after the first solenoid in combination with the focusing properties of the solenoid acts as an additional energy filter. By combining the aperture with the energy filter it is possible to dump most of the low energy electrons. In Figure 5 a typical CT measurement can be seen, where

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the scales are different for the different signals. The pink curve is the signal out from the gun corresponding to a total charge of about 300 nC. The chopper in combination with the aperture cuts the beam, the blue signal corresponds to the signal after the chopper and aperture, and has total charge of 3.5 nC. The yellow curve shows the signal after the energy filter, i.e. what is sent into the first LINAC structure, and the total beam charge per shot is about 1 nC.

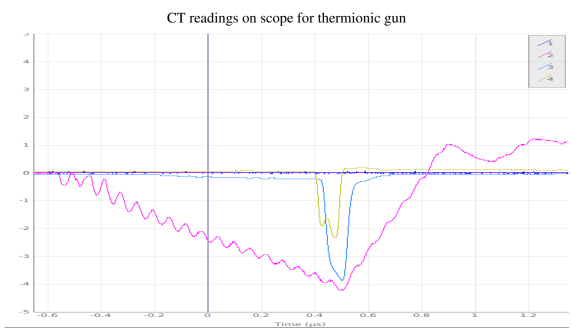

Figure 5: Beam current at the exit of the gun (pink), before (blue) and after (yellow) the energy filter, the scales for the vertical signal is different between the different channels.

The chopper was commissioned to produce the required bunch structure. Figure 6 shows the induced signal of a LINAC shot at a BPM strip. Here, the chopper operates at 100 MHz and it is configured for injection into ten 100 MHz storage ring buckets, and as can be seen the temporal pattern is ten buckets with 10 ns spacing. The emittance of the thermionic gun was not fully characterized at the time of this proceeding.

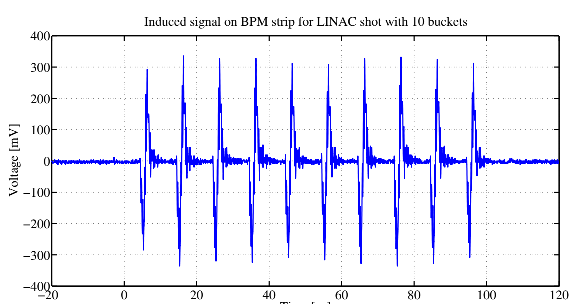

Figure 6: The induced signal of a LINAC shot at a BPM strip.

Photocathode Gun

The photocathode gun was also conditioned and initially commissioned in the MAX IV gun test stand. Figure 7 shows the measured charge out from the photocathode gun, as can be seen the delay is set so that the laser hits the cathode at the end of the RF pulse to maximize the field in the gun. The phase of the gun is set using a phase scan, and then set the delay stage of the laser system to a phase 30° from the zero-crossing. A typical phase scan result can be seen in Figure 8.

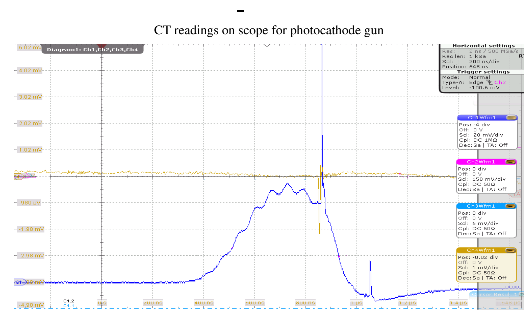

Figure 7: Typical charge output for the photogun.

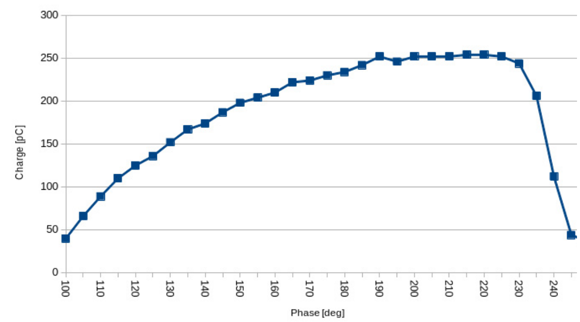

Figure 8: Typical phase scan for the photogun.

The quantum efficiency of the copper cathode was measured to be $2.2 \cdot 10^{-5}$ in the test stand and this was also the measured QE after the gun was moved and installed at the MAX IV site. At the moment there is no emittance diagnostics available close to the photocathode gun, the emittance is measured after the first three LINAC structures using the quad scan diagnostics available there. A plot of a quad scan result can be seen in Figure 9.

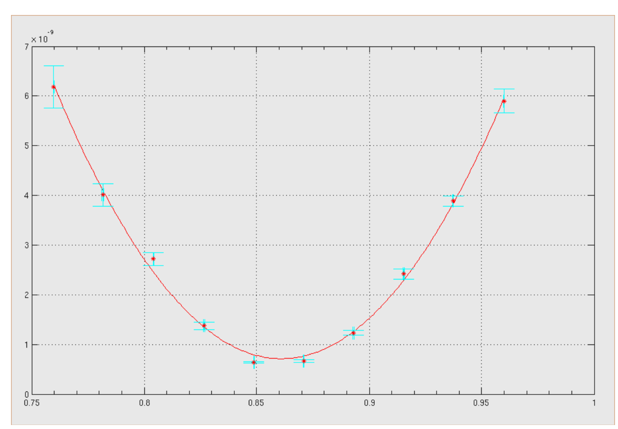

Figure 9: Typical quad scan curve at matching section one for the photocathode beam.

Initially the measured emittance out from the gun was higher than expected, measurements initially showed an

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emittance of around 6 mm mrad at 170 pC. After investigation it was believed that the laser pulse was shorter than earlier thought and by increasing the length of the laser pulse it was possible to get the emittance down to 1.5 - 2 mm mrad at 100 pC. Further investigations will be made to determine what causes the decrease of the emittance.

FURTHER INJECTOR COMMISSIONING STEPS

The optics of the thermionic injector are being evaluated to see if there is some improvement to be made, both from higher energy out from the gun and from another operating scheme. These are being evaluated based on the experience gained during the commissioning and how the machine is performing with the beam that is being forwarded.

For the SPF the emittance requirement is below 1 mm mrad. Work will continue to improve the emittance out from the gun, using the improved diagnostics and also using the experience gained from the MAX IV gun test stand where a gun of the same design as the commissioned photocathode gun is currently being operated. One step is a cathode program to increase the understanding of the performance of the cathodes and to carry out long time investigations of the cathode performance.

SUMMARY

The MAX IV injector for the MAX IV project contains one thermionic leg and one photocathode leg, and it has been commissioned during fall 2014 / spring 2015. Results of beam measurements after the initial commissioning shows that the injector is able to produce a photocathode beam of 100 pc at 1.6 mm mrad and a thermionic beam with the correct bunch structure for ring injection at 20 pC per S-band bunch.

Work will continue to optimize the beam parameters using the installed system and test systems available.

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