BEAM PERFORMANCE OF THE PHOTOCATHODE GUN FOR THE MAX IV LINAC

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Abstract

The MAX IV facility in Lund (Sweden) is under construction and conditioning of the electron guns for the injector is ongoing. There are two guns in the injector, one thermionic gun for storage ring injection and one photocathode gun for the Short Pulse Facility. In this paper we report on the beam performance tests of the photocathode gun. The measurements were performed at the MAX IV electron gun test stand [1] during spring 2014. Parameters that were studied includes quantum efficiency, emittance and emittance compensation. Results from the measurements are also compared to particle simulations done with ASTRA.

INTRODUCTION

The MAX IV facility [2] is under construction in Lund, Sweden and includes two storage rings for production of synchrotron radiation and a short pulse facility (SPF) [3]. Both storage rings and the SPF are injected from a full energy LINAC and the injector for the LINAC has two different guns, a thermionic gun and a photocathode gun. The thermionic gun is used for ring injection but due to the requirements of short bunches and the long tail of low energy electrons, the thermionic gun is unsuitable for injection to the SPF. A 1.6 cell photocathode gun will be used instead, based on the FERMI@Elettra [4] gun operating at a frequency of 2.9985 GHz.

One part of the commissioning of the facility is conditioning of the photocathode gun and measurement of basic beam properties to find the performance of the gun. The gun was conditioned during last part of 2013 and the measurements of beam parameters were done during the first half of 2014. In this article the results from these measurements will be presented and we compare some of them to simulated values. The goal of these measurements is to verify that the gun can perform well enough for the commissioning of the LINAC and the SPF operations. The requirement of the SPF is a beam energy of 3 GeV and a transverse normalised rms emittance of 1 mm mrad at the undulator entrance.

GUN TEST STAND

The photocathode gun was operated in the gun test stand at MAX IV. Measurements of beam energy were performed using a magnetic energy filter installed at the end of the test stand. The magnetic energy filter consists of two dipoles that bend the beam 120°. The setup in the gun test stand used for measurements of spot size, emittance and phase-charge curves is displayed in Fig. 1. The pepperpot used for the emittance measurements is installed between the beam viewers YAG1 and YAG2, at a distance of 1.45 m from the cathode.

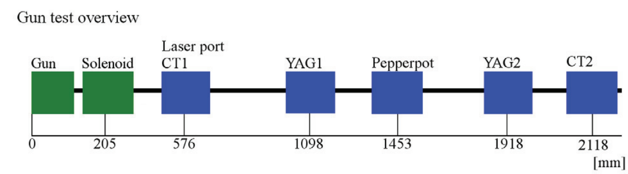

Figure 1: Schematic overview of the gun test stand.

The gun is powered by a klystron with a connected SLED cavity at 2.9985 GHz. The laser system is based on a Ti:Sapphire laser and the pulses are stretched, split and tripled to give a FWHM laser pulse length of 8 ps at 263 nm wavelength. The laser oscillator is locked to the 3 GHz signal of the RF system and the energy of the laser pulse can be changed during operation. The transport of the laser beam from the laser hutch to the cathode is done through air, the beam is then focused on the cathode through an aperture of 2 mm diameter. The laser is triggered to hit the cathode when the RF pulse has lasted long enough for the cavity to be filled, the precise injection phase is then controlled using a motorized optical delay stage.

SIMULATIONS

Simulations were made using ASTRA [5] with 10 000 particles, and the fields used to describe the gun and the solenoid are based on measured fields. The beam properties depend on the laser phase, the spot size, the electric field in the gun, as well as other parameters, so a number of different simulations were run for different settings to understand the behavior of the gun. The results for simulations of beam energy as function of the electric field for an injection phase of 10°, corresponding to the setting for the energy measurement, can be seen in Fig. 2.

To understand the phase-charge relation for the gun, simulations were made with a maximum electric field strength at the cathode of 90 MV/m to determine the charge as a function of the injection phase. ASTRA was used to determine the number of accelerated electrons as a function of the injection phase and this result combined with a field dependent charge curve gives an estimate of the phase-charge relation. These simulations do not fully account for the Schottky effect and shielding effects, so the amount of charge is

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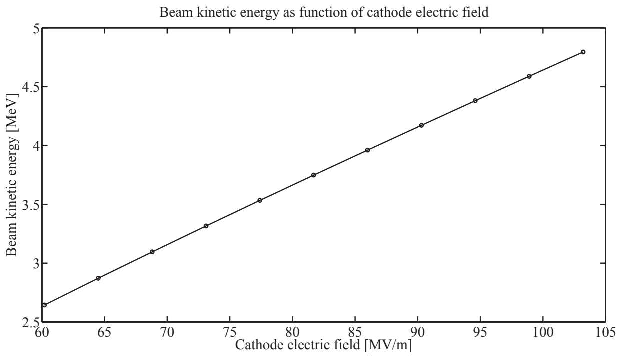

Figure 2: Simulated beam kinetic energy as function of cathode electric field.

an approximation. One result from the simulation for 90 MV/m and 100 μJ laser energy can be seen in Fig. 5 together with the results from the measurements.

To investigate the emittance dependence on the injection phase, simulations were made with an electron beam corresponding to a gaussian transverse symmetric beam size with a FWHM of 0.8 mm. These simulations were made with the same setting for the solenoid field strengths as the measurements, 0.198 T at 90 MV/m and 0.190 T at 86 MV/m, to be able to compare the results. The results at two different beam charges can be seen in Fig. 3 and Fig. 4.

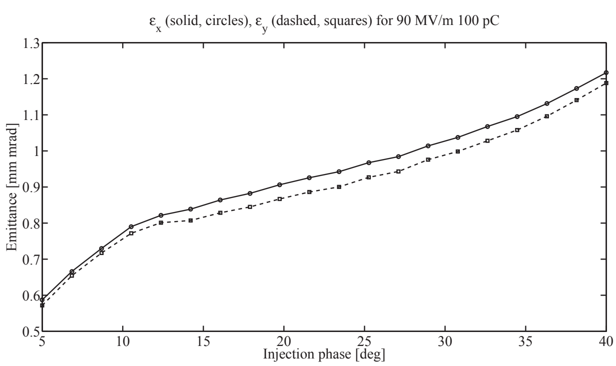

Figure 3: Simulated transverse normalised rms emittance for 90 MV/m and 100 pC charge.

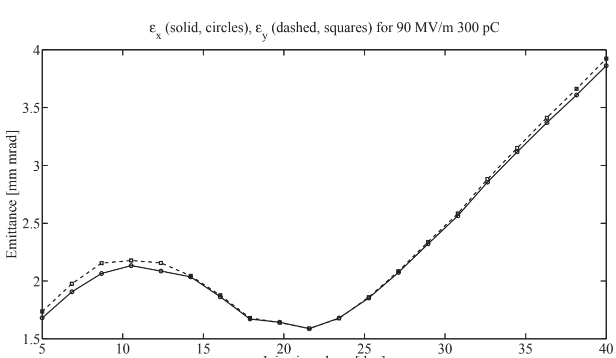

Figure 4: Simulated transverse normalised rms emittance for 90 MV/m and 300 pC charge.

MEASUREMENTS

Charge is measured using 250 MHz integrated current transformers (CT1 and CT2) connected to an oscilloscope, or using a Faraday cup. The beam viewers used were YAG crystals and CCD cameras and all measurement devices were triggered by the same signal and individual delays.

Energy

The energy of the electrons was measured using the magnetic energy filter. For a given RF power to the gun [setting of the modulator], the corresponding beam energy could be found by the current provided to the dipoles in the energy filter. The results are in Table 1 at an injection phase of approximately 10°.

Table 1: Energy Measurements

Modulator voltage [kV]	Kinetic energy[MeV]	Max E-field at cathode [MV/m]
22	3.4	77
23	3.8	82
23.5	4.0	86
24	4.2	90

The maximum electron energy in these measurements was 4.2 MeV. The total energy spread is about 0.6 MeV in all measurements but it is uncertain to what degree dark current electrons contribute to this energy spread. Compared to simulations this matches to a maximum electric field in the main cell for 23.5 kV of around 100 MV/m and for 24 kV of around 105 MV/m. This corresponds to a maximum electric field on the cathode of 86 MV/m and 90 MV/m.

Laser Phase - Charge

The injection phase is set using an optical delay stage in the laser system. To calibrate this setting a step-charge scan was made, the charge was measured using CT1 for different injection phases. The result can be seen in Fig. 5.

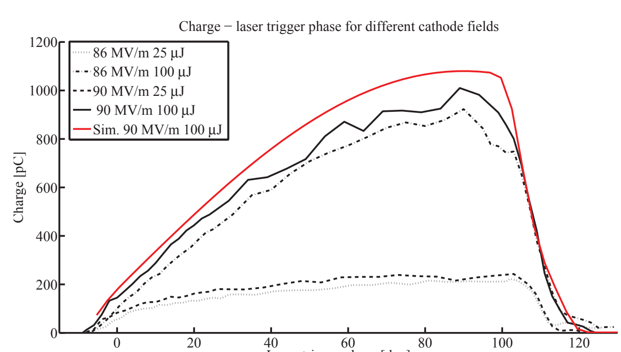

Figure 5: Measured charge as function of laser phase.

Comparing the measurements with simulations, they correspond with an offset of about 10 °. The phase setting where beam charge is first measurable is approximately an injection phase of -10°, +/- 2°. Since the laser pulse is

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about 10° in length, the phase where charge is first measured should correspond to an injection phase of around -10°. These settings for the laser trigger could then be used to set the phase for the following simulations. It was noted during the experiments that this setting is not stable over time, it seems to be moving +/- 2° over a period of 5-10 minutes, so the calibration was remade for each new measurement to keep it as close as possible to the correct values.

Quantum Efficiency

Scans of the beam charge as a function of laser energy were performed for different electric field strengths in the gun to determine the quantum efficiency. The result is displayed in Fig. 6, for four different field settings.

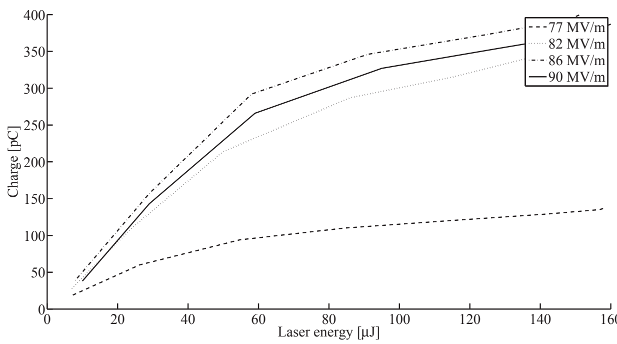

Figure 6: Measured charge as function of laser energy.

The emitted charge from the cathode will shield the cathode, and the lower electric field on the cathode leads to lower emission. This can be seen from the non-linear behavior of the charge in Fig. 6, the dependence of emitted charge of laser energy should in principle be linear without the effect from the space charge limitation.

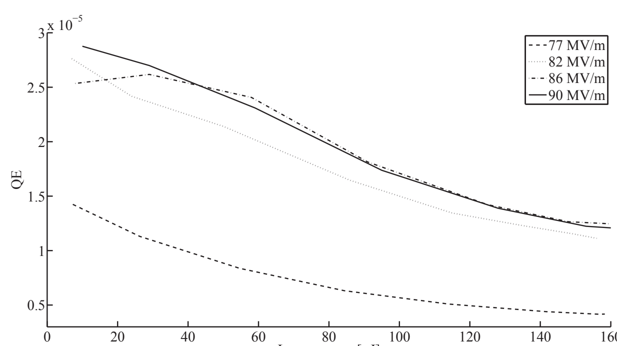

Figure 7: Measured quantum efficiency as function of laser energy.

The quantum efficiency is plotted in Fig. 7 for different field strengths. As can be seen the QE seems to be dependent both on the field in the gun and on the laser energy. The dependence of the QE on the electric field is the result from the Schottky effect. The Schottky effect will reduce the work function of the material in the cathode. A more detailed discussion can be found for example in [6].

On average the QE for the cathode turns out to be around $2 \cdot 10^{-5}$ for an electric field on the cathode in the 86 - 90 MV/m range.

Emittance

The beam transverse normalised rms emittance was measured using the pepperpot technique, using a with the mask set at 1.45 m from the cathode and 0.47 m from YAG2. The pepperpot used in the measurements had a grid size of 1 mm, a hole diameter of 100 μm and a thickness of 0.5 mm. Pepperpots with finer masks and holes were manufactured but could not be used due to inadequate quality.

The solenoid field was adjusted so the image of the pepperpot on YAG-2 contained a at least 9 beamlets from the pepperpot. Due to the large grid size of the available pepperpot we had to set the solenoid to give a spot size of around 4 mm at the pepperpot plane, this is a non-optimal working point. This means the emittance measured is not properly optimized. The charge is kept constant for each measurement, that is the laser energy is adjusted for each injection phase setting in the measurements to keep the charge independent of the injection phase.

The background was subtracted from the images, though the signal was still quite noisy after filtering. There were also quite large shot to shot fluctuations in the images, and to minimize this effect the images chosen for the analysis have a good number of beamlets. The analysis was made using the method presented in Zhang [7], where beamlets are summed in the x- respective y-direction.

The dependence of the emittance on the injection phase was measured for two different fields and two different charges. The emittance is measured at electric fields on the cathode of 86 MV/m and 90 MV/m, corresponding to a maximum electric field amplitude of 100 MV/m and 105 MV/m in the main cell. The results can be seen in Figs. 8, 9 and 10.

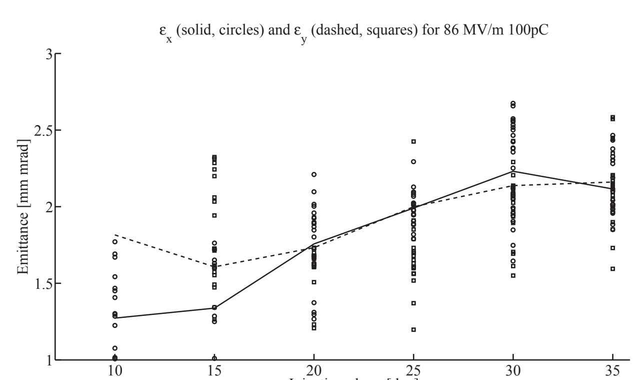

Figure 8: Measured emittance as function of injection phase for a maximum electric field on the cathode of 86 MV/m and 100 pC charge.

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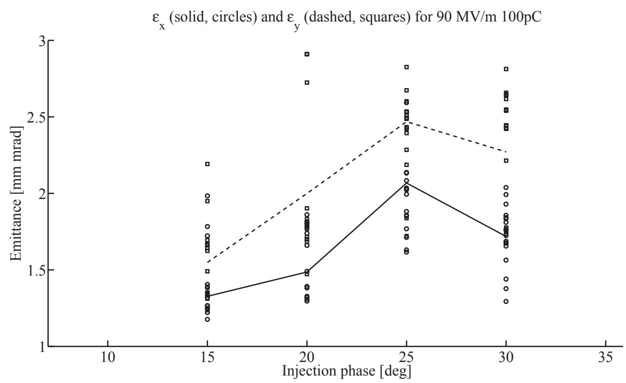

Figure 9: Measured emittance as function of injection phase for a maximum electric field on the cathode of 90 MV/m and 100 pC charge.

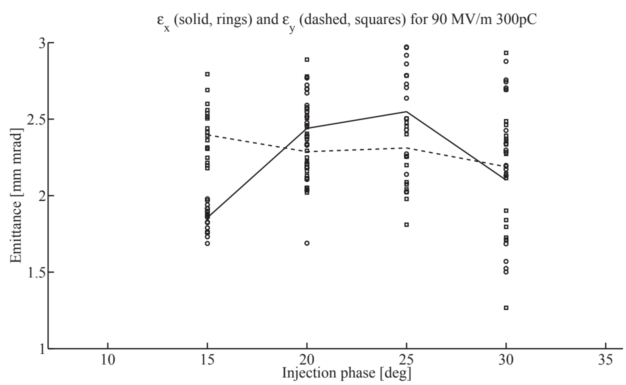

Figure 10: Measured emittance as function of injection phase for a maximum electric field on the cathode of 90 MV/m and 300 pC charge.

These measurements show little similarities with the simulations in Figs. 3 and 4. There might be many causes for this for example uncertainty of the effective laser spot size, energy and emission properties of the cathode. Future experiments and measurements will be done to try to match the simulations and measurements.

SUMMARY

The gun can provide a beam of around 4 MeV energy with an non-optimized emittance at likely injection phases of 1.5 - 2.5 mm mrad. We believed that the emittance at the optimized setting will be below 1 mm mrad. The quantum efficiency for the cathode in the gun with electric fields at the cathode between 85 and 90 MV/m is approximately $2 \cdot 10^{-5}$.

There are large shot to shot fluctuations in the measurements, affecting among other things the emittance measurements. These fluctuations are probably caused by fluctuations in the laser energy or timing issues.

FUTURE WORK

For the current gun design the next planned step is to put an existing emittance meter [8] into operation to characterize the emittance along the injector. The goal is to be able to measure the emittance and the spot size along the first 2-3 meters of the injector to be able to match the gun settings to the Ferrario working point [9].

The slits in the emittance meter have smaller dimensions than the pepperpot used in these measurements so the new setup will be able to measure the emittance at a more optimal working point of the gun.

Parallel to the work with the emittance meter, the collection and analysis of the measured data will be improved. It will also be investigated if there are possible ways to limit the shot to shot fluctuations in the setup and if so, how to implement these.

The models used in the simulations will be reviewed to see if there is anything that can be improved, and once the emittance meter is operational data from measurements will be used to improve the matching to simulations.

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