EXPERIMENTAL CHARACTERIZATION OF THE ELECTRON SOURCE AT THE PHOTO INJECTOR TEST FACILITY AT DESY ZEUTHEN*

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Abstract

The Photo Injector Test facility at DESY Zeuthen (PITZ) was built in order to study the production of high brightness electron beams, which are substantial for the successful operation of Free Electron Lasers (FEL) and linear colliders. The photoinjector at Zeuthen is based on a 1.5-cell L-band rf cavity with coaxial rf coupler equipped with emittance compensating solenoids, a laser capable to generate long pulse trains, an UHV photo cathode exchange system, and various diagnostics tools. The current goal of PITZ is a full characterization of the electron source, which will be installed at the TESLA Test Facility Free Electron Laser (TTF2-FEL) in autumn 2003. In the running periods before the gun is delivered to TTF2-FEL, the rf performance and the beam parameters will be measured in detail. The results presented in this contribution contain the measurements of dark current, driving laser parameters, beam charge, beam size along the facility, transverse emittance, momentum and momentum spread. The electron beam measurements will be presented in comparison with beam dynamics simulations.

INTRODUCTION

In January 2002 the first photoelectrons were produced at the photoinjector test facility at DESY Zeuthen [1]. The current near term goal of PITZ is to do a full characterization of the existing electron source and then to install it at the VUV-FEL at TTF2 in Hamburg in autumn 2003. The schematic overview is presented in Fig. 1.

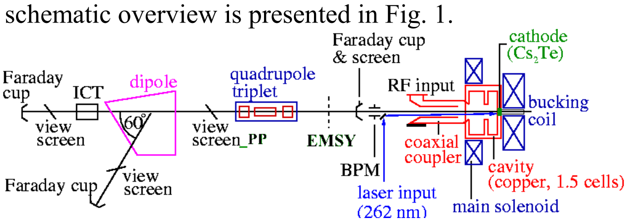

Figure 1: Schematics of the current set-up.

ACHIEVEMENTS ON RF COMMISSIONING

A smooth commissioning procedure, partially using an automatic conditioning program (ACP) [2], yields an operation with up to 900 μs long rf pulses at 10 Hz repetition rate and a gradient of about 40 MV/m. That corresponds to a maximum averaged power of 27 kW in the gun cavity with 0.9% duty cycle [3,4].

The dark current in the gun cavity has been measured as a function of the accelerating gradient, main solenoid and bucking magnet currents [4]. Measurements were performed using Mo and Cs_2Te cathodes (Fig. 2). With a rf electric field of ~40.5 MV/m and a main solenoid current of 200 A, the dark current for Cs_2Te is about 180 μA.

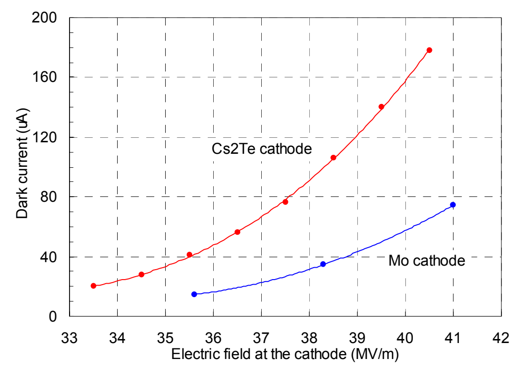

Figure 2: Maximum dark current measured as a function of the electric field at the cathode.

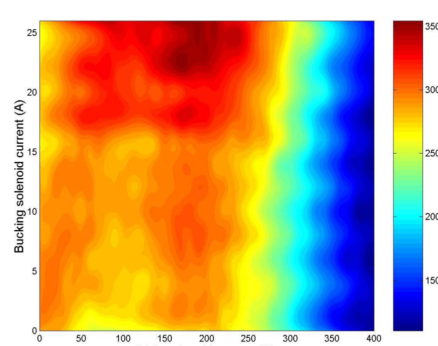

Figure 3: Contour plot of the dark current at 40 MV/m for the Cs_2Te cathode as a function of main solenoid and bucking solenoid currents.

Results of a detailed study of the dark current dependence on the magnetic field of main and bucking solenoids are presented in Fig.3.

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PHASE SCAN

The PITZ driving laser is able to generate trains of micro pulses of up to 800 μs length. The actual temporal profile (gaussian shape) of the laser micro pulses in the UV was measured using a streak camera to be about (7±1)ps FWHM. The transverse profile of the laser beam can be varied and typical rms transverse sizes of ~0.5 mm can be obtained.

The laser shape determines significantly the photoelectron phase scan – the dependence of the number of accelerated photoelectrons on the rf launch phase. The beam charge measured by the first Faraday cup (0.78 m from the cathode) is shown in Fig. 4 for two different main solenoid currents.

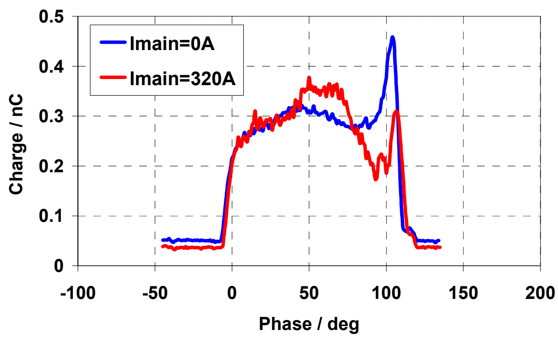

Figure 4: Measured beam charge as a function of rf phase. Gradient at the cathode 40 MV/m.

A two dimensional phase scan – measured beam charge as a function of rf phase and main solenoid current - is presented in Fig. 5.

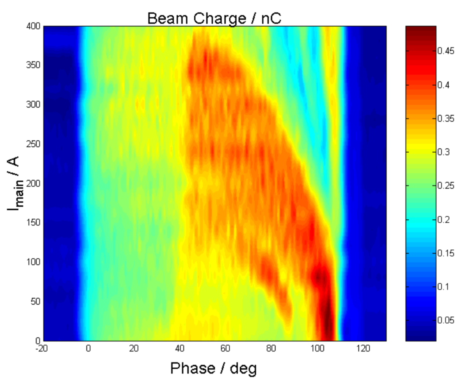

Figure 5: 2D phase scan - contour plot of the measured beam charge as a function of rf phase and main solenoid current. Gradient at the cathode 40 MV/m.

At zero solenoid field the peak at the right side of the phase scan (low beam energies) could be explained by focusing effects of the rf field. For increasing solenoid fields higher beam energy is needed to have a good transmission through the cavity. A particle tracking code ASTRA [5] was used to simulate the beam charge dependence. The result is shown in Fig. 6. According to simulations for the actual driving laser beam parameters and main solenoid longitudinal position, features of the phase scan are caused by particle loses at the photocathode (due to high space charge) or at cavity and beam line apertures.

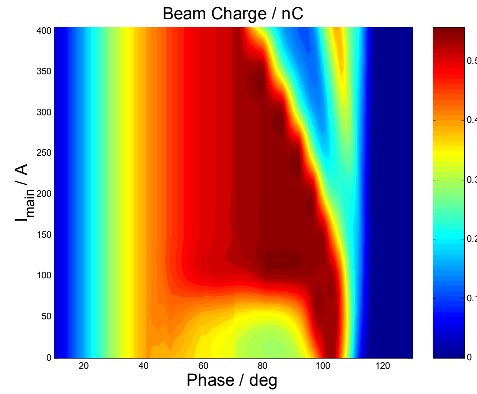

Figure 6: Simulated 2D phase scan - contour plot of the beam charge as a function of rf phase and main solenoid current. Gradient at the cathode 40 MV/m.

LONGITUDINAL MOMENTUM MEASUREMENT

The mean momentum and the momentum distribution of the electron beam were measured using the dipole spectrometer. The mean beam charge used was about 1 nC, the accelerating gradient at the cathode was 40.5 MV/m [6]. The dependence of the measured mean momentum and the momentum spread as a function of the rf phase compared to simulations is shown in Fig. 7.

The smallest momentum spread of 15 keV/c for 1 nC is measured at rf phase of ~ 15°.

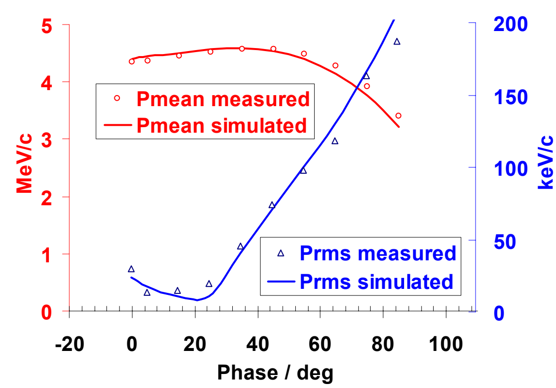

Figure 7: Mean momentum (left axis) and momentum spread (right axis) as function of the rf phase in comparison with simulation.

TRANSVERSE SIZE MEASUREMENTS

The rms size of the electron beam has been measured at different screens along the beam line. Dependences of the beam size at the screen of EMSY and screen_PP (1.62 m and 2.63 m from the cathode, respectively) on the main solenoid current are shown in Fig. 8. Rough estimations for the transverse emittance X/Y for main solenoid currents of 290A/292A yield normalized transverse emittances of (2.8±0.9) / (3.0±0.9) π-mm-mrad, respectively.

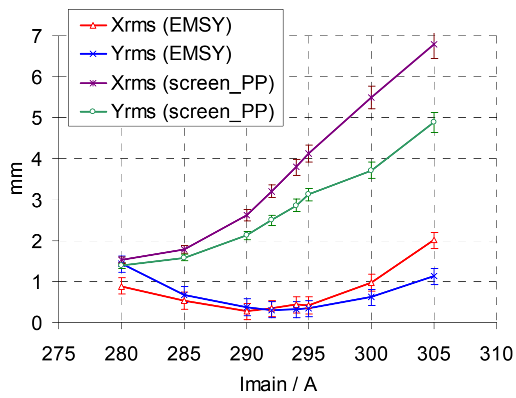

Figure 8: Measured beam spot sizes as function of the main solenoid current. Gradient at the cathode 40 MV/m, beam charge 0.5 nC.

The transverse beam size ($R_{rms} = \sqrt{X_{rms}^2 + Y_{rms}^2}$) measured at screen_PP as a function of the rf phase for different solenoid currents is shown in Fig. 9.

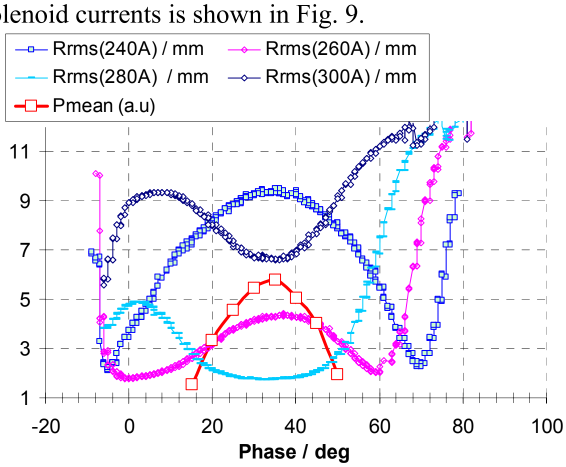

Figure 9: Measured beam spot sizes as function of the rf phase for different main solenoid currents. Gradient at the cathode 40 MV/m, beam charge 0.5 nC.

The longitudinal mean momentum dependence on the rf phase is shown on the same plot. It has a maximum at the phase of the local maximum of the beam spot size (minimum for higher solenoid currents). This is explained by the dependence of the solenoid focusing properties on the beam energy and was confirmed by corresponding simulations. Such a beam size phase scan can serve as an efficient tool for obtaining the phase of the maximal energy gain, since it is significantly faster than momentum measurements using dipole and dispersive arm.

TRANSVERSE EMITTANCE MEASUREMENTS

Measurements of the transverse emittance were performed using a single-slit diagnostics. Beamlet profiles were observed 1010 mm downstream of a single-slit mask (1 mm thick tungsten plate, 50 µm slit opening) at screen_PP [7]. The transverse emittance was measured as function of the main solenoid current. The results are shown in Fig. 10.

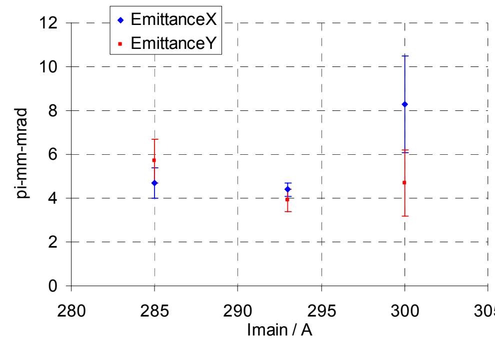

Figure 10: Measured transverse beam emittance as a function of the main solenoid current. Gradient at the cathode ~40 MV/m, beam charge ~0.5 nC.

The measured emittance values correspond to simulation predictions of the minimum achievable emittance of ~3 π-mm-mrad for the present short laser duration (7 ps FWHM). These values are different from the ones obtained earlier [8] because the laser beam parameters have been changed. Emittance improvement will be obtained by driving laser parameters optimization (temporal flat-top profile with short rise/fall times) as foreseen in the next months.

SUMMARY AND OUTLOOK

The experimental characterization of the electron source at the photoinjector test facility at DESY Zeuthen is ongoing. A maximum average power of 27 kW in the gun with a duty cycle of 0.9% has been achieved. Detailed measurements of dark current, beam longitudinal momentum and transverse phase space have been discussed.

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