FIRST MEASUREMENTS AT THE PHOTO INJECTOR TEST FACILITY AT DESY ZEUTHEN*

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Abstract

The **P**hoto **I**njector **T**est facility at DESY **Z**euthen (PITZ) is built to develop electron sources for free electron lasers and future linear colliders. The main goal is to study the production of minimum transverse emittance beams with short bunch length at medium charge (~1nC). The facility includes a 1.5 cell L-band cavity with coaxial rf coupler and solenoid for space charge compensation, a laser capable to generate long pulse trains, an UHV photo cathode exchange system, and different diagnostics tools. Besides an overview of the facility, its main components and their commissioning, this paper concentrates on the first measurements with and without photo electrons. This includes measurements of the rf performance, dark current, laser parameters, beam charge, electron momentum, beam size, and first results on the commissioning of the emittance measurement system.

1 INTRODUCTION

In autumn 1999 it was decided to built a photo injector test facility at DESY Zeuthen [1] and in January 2002 the first photo electrons were produced. The major near term goal of the facility is to develop and study an electron source for the TESLA Test Facility Free Electron Laser (TTF-FEL). The main focus is on the production of minimum transverse emittance beams at a charge of about 1 nC. In order to further increase the charge density in downstream bunch compressors the longitudinal phase space is also of importance. Detailed experimental analysis of the transverse and longitudinal phase space after the gun will allow benchmarking tests of the theoretical understanding of photo injectors. With PITZ extensive R&D on rf guns will be possible at DESY in parallel to the operation of TTF-FEL. This also includes the test of new developments on e.g. lasers, beam diagnostics, and photo cathodes. In future, studies on the production of flat beams and polarized electrons for the TESLA project are foreseen.

Details of the hardware components of PITZ are describes elsewhere [2]. Only the schematic overview is presented here, see the figure below.

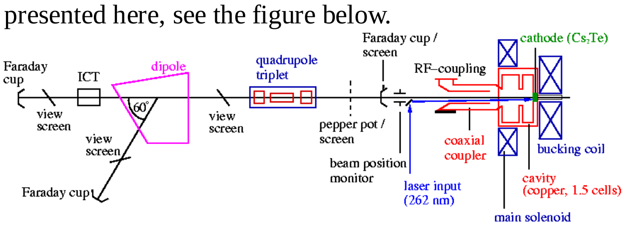

Figure 1: Schematics of the current set-up.

2 ACHIEVEMENTS ON RF COMMISSIONING

In a smooth commissioning procedure with an automatic conditioning program [3] a stable operation with a 400 µs long rf pulse at a 5 Hz repetition rate has been obtained. In future, the rf pulse length will be extended to above 800 µs which requires further adjustment of the water cooling system of the gun. The maximum gradient achieved by the existing rf system was about 34 MV/m at full pulse length and repetition rate. This was limited by the high voltage power supply of the rf system which will be replaced in June 2002.

For the conditioning work the usual Cs_2Te cathode is replaced by a molybdenum cathode [4, 5]. The dark current emission from the cavity including the Mo cathode has been measured at the first Faraday cup as a function of the electric field gradient at the cathode position for different settings of the main solenoid (see Figure 2). The bucking coil current was chosen to make the static magnetic field zero at the cathode location. A maximum dark current of about 35 µA was obtained for about 34 MV/m at the cathode. As expected, the dark current is over focussed at higher solenoid settings (>250 Ampere) which are the standard values for a 1 nC beam operation.

A Fowler-Nordheim analysis including a linear fit to the rescaled data results in a field enhancement factor of about 300, mainly independent of the chosen solenoid setting.

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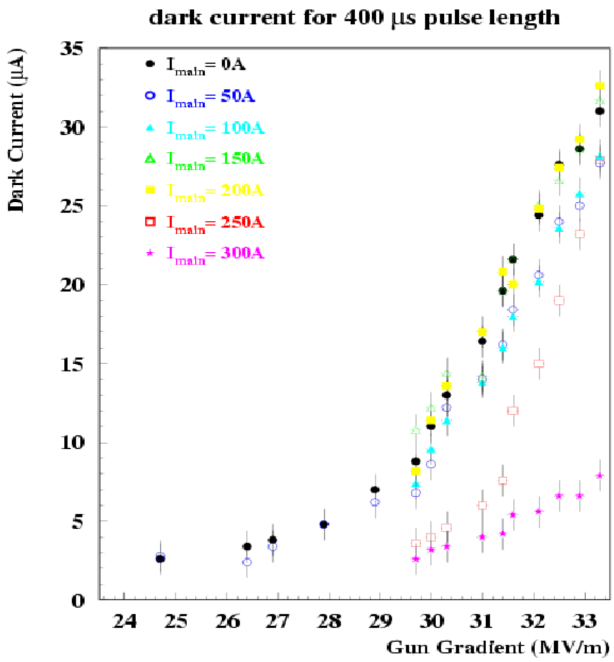

Figure 2: Dark current measurements, see text.

3 THE LASER SYSTEM

The schematic of the laser system currently in operation is shown in Figure 3. It is able to generate trains of micro pulses up to 800 µs length. Figure 4 shows an oscilloscope picture from the pulse train oscillator output (lower curve) and the 800 µs long pulse train at the end of the amplifier chain (upper curve).

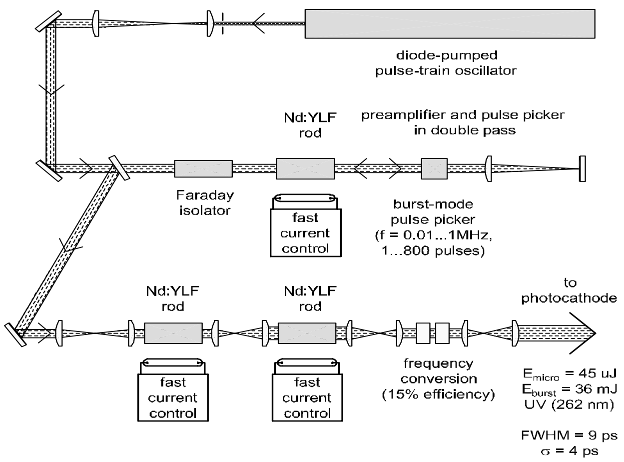

Figure 3: Optical scheme of the current PITZ laser.

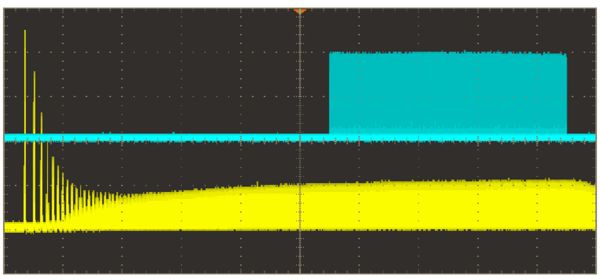
Figure 4: Generation of laser pulse trains, see text.

The temporal shape of the laser micro pulses in the UV was cross-checked with a streak camera measurement. It results in a FWHM of about 10 ps as shown in Figure 5.

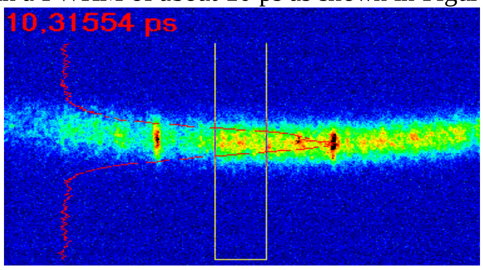

Figure 5: Streak camera picture of laser micro pulses.

The transverse profile of the laser beam at the position of the cathode is measured by means of a splitting plate just before the laser beam enters the vacuum system. The rms laser spot size at the so called ‘virtual cathode’ was measured to be about 0.6 mm.

Detailed numerical studies employing the simulation tools ASTRA and MAFIA TS have shown that the PITZ injector layout is capable of producing low emittance beams. In order to achieve a normalized transverse emittance of less than 1.0 mm-mrad at a charge of 1 nC a 20 ps FWHM flat-top longitudinal laser profile with rise times below 2.0 ps is required [6, 7]. This is the goal for the ongoing laser development for PITZ at the Max-Born-Institute.

In addition, the simulations show that initial laser spot offsets exceeding 1.0 mm result in significant beam emittance growth [8]. Therefore, the ‘virtual cathode’ together with the remote controlled laser beam adjustment plays an important role [9].

4 MEASUREMENTS WITH BEAM

After the first photoelectrons were produced in January 2002, different diagnostic tools have been commissioned and first measurements have been taken.

4.1 Charge

The charge of the electron beam is measured using a Faraday Cup which collects the beam charge and an oscilloscope to integrate over the current signal. In the first running period beam charges of the order of 5-30 pC were obtained. After exchanging the photo cathode up to about 0.8 nC were produced.

4.2 Beam Size

The beam size of the electron beam was measured at different screen locations along the beam line. As an example, a rms beam size in x and y of 1.1 mm was obtained about 2 m downstream of the photo cathode using a setting of the main solenoid of 180 A. This number was compared to an ASTRA simulation [10] taking into account the gradient of the cavity, the longitudinal and transverse laser shape on the cathode, the produced charge, and the solenoid settings. The simulation yields a rms beam size (x and y) of 1.2 mm which is in good agreement with the measurement.

4.3 Momentum

A maximum momentum of about 4.0 MeV/c was measured with a spectrometer dipole [11]. The measured rms momentum spread of about 13 keV/c at a charge of about 30pC represents the resolution limit of the spectrometer due to an optical mismatch which will disappear at higher charges.

4.5 Emittance

A first emittance measurement at a beam charge of a few pC was performed using a multi slit mask diagnostic. Beamlet profiles (Figure 6) were observed about 1 m downstream of the multi slit mask (1 mm thick tungsten plate, 50 µm slit opening, 0.5 mm slit-to-slit spacing). Three different methods for evaluating the rms emittance were used. The first applies formulae which employ only geometrical parameters of the slit masks, beamlet sizes, and intensity distribution on the screen of observation [12]. For the second method the beam's rms size was measured directly at the position of the slit mask. The rms divergence and covariance of the transverse phase space distribution were obtained by analysing the beamlet profiles as for method 1. For method three, the emittance was evaluated as a product of the measured rms beam size and the weighted average of the rms divergence of the 3 different beamlet distributions. The results of the calculations are summarized in Table 1.

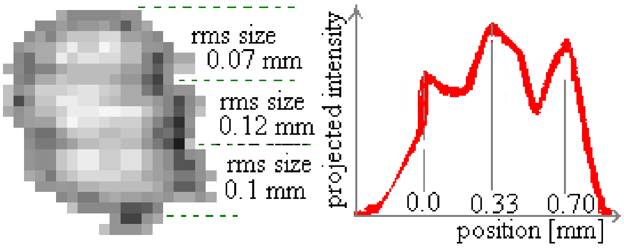

Figure 6: Beamlet picture and projection.

rms values	M 1	M 2	M 3
beam size [mm]	0.39	3.1	3.1
Divergence [mrad]	0.17	0.17	0.1
Covariance [mm mrad]	0.057	0.057	---
norm. emittance [mm mrad]	0.27	3.77	2.17

Table 1: Emittances for methods 1 to 3, see text.

The main difference between the emittance results comes from the different numbers for the estimated beam size. There are two effects which can explain the big differences: First, using just the beamlets with method 1 leads to an incomplete sampling of the transverse phase space. Secondly, the very low charge used during the measurement results in a low signal to noise ratio. Especially the beam size measurement at the slit mask position has a large uncertainty (method 2 and 3), while no dark current was observed downstream after the multi slit mask was inserted. To obtain a unique and reliable number on emittance more studies are needed and a sequence of measurements has to be taken for different injector settings.

5 SUMMARY AND OUTLOOK

We have shown that the photo injector test facility at DESY Zeuthen has gone into operation and have presented the first measurements with and without photo electrons. The rf commissioning reached up to 5 Hz repetition rate with a pulse length of 400 µs and a gradient of about 34 MV/m. A dark current of up to 35 µA was measured. A first version of the photo cathode laser system was commissioned, delivering up to 800 µs long pulse trains with a micro pulse length of about 10 ps. Beam charges from the pC to the nC scale have been produced and the evolution of the beam along the beam line has been measured. The maximum electron momentum obtained was 4.0 MeV/c. First results from the commissioning of the emittance measurement system have been presented, too. All this is of course only a first start and a longer operation and optimisation program is ongoing. Until spring 2003 the complete characterisation of the rf gun is foreseen and afterwards the set-up will be extended by the installation of a booster cavity.

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