FIRST BEAM 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) was built to develop electron sources for the TESLA Test Facility Free Electron Laser (TTF-FEL) 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, a 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 contribution will concentrate on the first measurements at PITZ with photo electrons. This will include measurements of the transverse and longitudinal laser profile, charge and quantum efficiency, momentum and momentum spread, transverse electron beam profiles at different locations and first results on transverse emittance.

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1. INTRODUCTION

In autumn 1999 it was decided to build a photo injector test facility at DESY Zeuthen [1]. In January 2002 the first photo electrons were produced. The current major goal is to develop and study an electron source for the TESLA Test Facility Free Electron Laser (TTF-FEL). Here, emphasis is taken on the production of minimum transverse emittance beams at a charge of about 1 nC. Detailed experimental analysis of the transverse and longitudinal phase space will allow benchmarking tests of the theoretical understanding of photo injectors. Using PITZ extensive R&D work on rf guns will be possible at DESY in parallel to the operation of TTF-FEL. This includes the test of new developments on e.g. lasers, beam diagnostics, and photo cathodes. In future, investigations on the production of flat beams and polarized electrons for the TESLA project are foreseen.

A description of the set-up and of the hardware components of PITZ are described elsewhere [2]. The schematic overview is presented in Fig. 1.

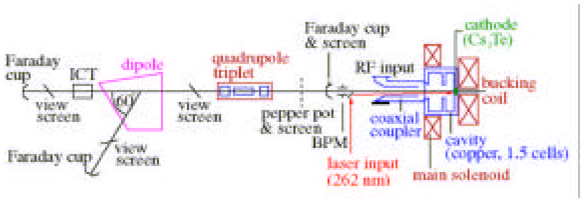

Figure 1: Schematics of the current set-up.

2. ACHIEVEMENTS ON RF COMMISSIONING

In a smooth commissioning procedure using an automatic conditioning program [3] a stable operation with a 400 μs long rf pulse at a 5 Hz repetition rate and a gradient of 34 MV/m has been obtained. In future, the rf pulse length will be extended to above 800 μs. The maximum gradient achieved by the existing rf system was about 37 MV/m at 100 μs pulse length and 1 Hz repetition rate. A more detailed description of the conditioning procedure, its results and dark current measurements is given in [4].

The dark current emission from the cavity has been measured as function of the electric field gradient at the cathode position for different settings of the main solenoid. The bucking magnet current was chosen accordingly to give a zero static magnetic field at the cathode plane. Measurements were performed using the photo emission Cs_2Te cathode. A maximum dark current of about 180 μA was observed for gradients of 35 MV/m, 1Hz repetition rate and 100 μs pulse length. For the conditioning work the usual Cs_2Te-cathode is replaced by a Mo-cathode [5,6]. The dark current emission from this cathode was measured to be a factor of 2 lower than for the Cs_2Te-cathode.

3. THE LASER SYSTEM

The schematic of the laser system currently in operation is shown in Fig. 2. The laser is able to generate trains of micro pulses of up to 800 μs length.

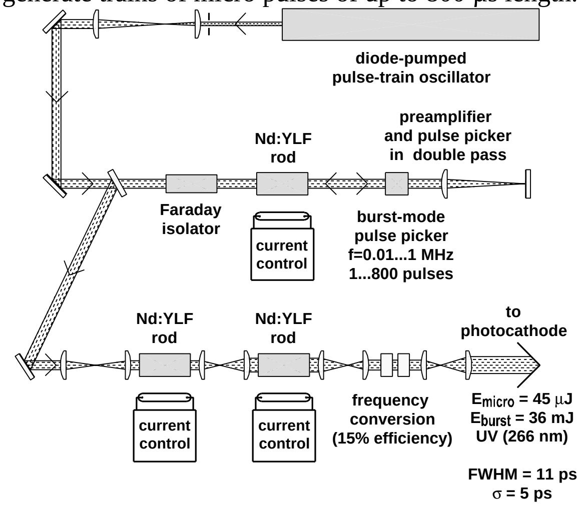

Figure 2: Optical scheme of the current PITZ laser.

The temporal profile (gaussian shape) of the laser micro pulses in the UV was measured using a streak camera to be about 10 ps FWHM.

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' [7] was measured to be about 0.6 mm in general. For the beam size and emittance measurements a rms transverse size of 0.25 ± 0.15 mm was obtained (gaussian shape in all cases).

Simulations have shown, that a smaller emittance is achievable, if both, the transverse and longitudinal laser profile are flat [8, 9]. Therefore, an important goal of the ongoing laser development at the Max-Born-Institute is to produce a longitudinal flat profile of a length of about 20 ps and a rise time below 2 ps.

4. MEASUREMENTS WITH ELECTRON BEAM

4.1 Charge and quantum efficiency

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. Mean charges from the pC scale up to 4.7 nC were obtained.

A first measurement of quantum efficiency for only one value of charge was performed. For 36 MV/m and a main magnet current of 240 A a mean charge per bunch of (0.9 ± 0.1) nC was measured. The laser pulse energy of a single bunch in a bunch train of ten bunches was estimated to be (1.0 ± 0.1) µJ at the cathode. This results in a quantum efficiency of the order of 0.5 %.

4.2 Momentum

In Fig. 3 the momentum distribution of the electron beam accelerated at a gradient of about 35 MV/m and measured using the dipole spectrometer is shown. The mean charge is about 0.4 nC. A detailed methodical outline of the momentum measurement can be found in [10]. For a gradient of about 37 MV/m the current maximum beam momentum of about 4.3 MeV/c is obtained.

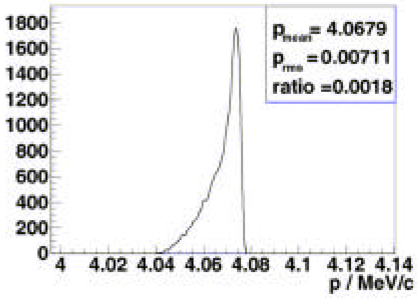

Figure 3: Momentum distribution for a gradient of about 35 MV/m and a mean charge of about 0.4 nC.

The rms momentum spread as function of the number of integrated pulses in a bunch train of constant charge is shown in Fig. 4. It is about 8 keV/c for a low number of pulses. The increase of the measured overall momentum spread with the number of pulses could be caused by an instability of the rf gradient or of the phase relation between laser and rf or by a transverse beam jitter.

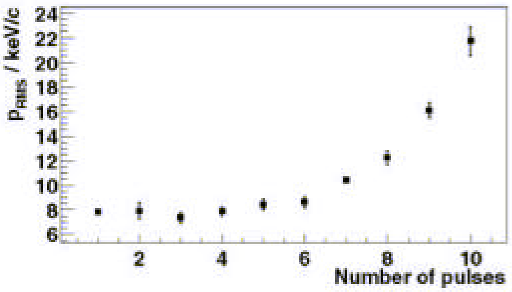

Figure 4: Momentum spread as function of the number of pulses in the laser bunch train at a bunch charge of about 0.4 nC.

4.3 Electron Beam Size and Simulations

The size of the electron beam was measured at different screen locations along the beam line, see Fig. 5. The measurement conditions are summarized in Table 1 and in the chapter on the laser system. For these conditions ASTRA simulations were run and compared to the data.

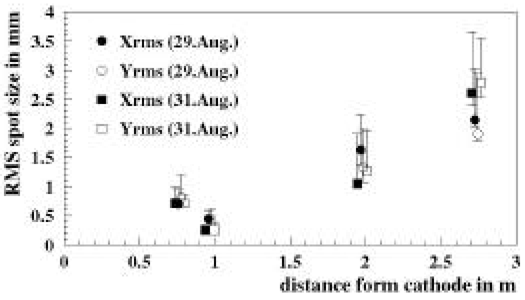

Figure 5: Two measurements of beam spot sizes along the beam line under similar operation conditions. The measurements at each of the four locations are slightly displaced to show them more clearly.

All the simulations with input parameters according to the measured numbers (Tab. 1) can predict a beam waist around 1 m distance from the photo cathode but the absolute beam size is not good reproduced, especially for the last two points of observation. Here, the simulation always predicts larger sizes. Also the measured momentum distributions and emittances (see Table 1) can not yet be reproduced by the simulations. These problems need more study in future. They might be related to the very high space charge effects at the cathode (note small laser beam size) which could also explain the loss of charge from the cathode down the beamline.

4.4 Transverse emittance measurements

Measurements of the transverse emittance were performed using a multi-slit diagnostics. Beamlet profiles were observed 1010 mm downstream of a multi-slit mask (1 mm thick tungsten plate, 50 µm slit opening, slit-to-slit separation: 1.0 mm for vertical slits and 0.5 mm for horizontal slits).

The emittance was evaluated as a product of the RMS beam size and the RMS uncorrelated divergence. The beam size is measured directly at the location of the multi-slit mask, the divergence is determined by analysing the beamlet profiles. Since the beamlets are partially overlapping, their individual sizes are deduced by fitting the overall profile to a mixture of gaussian functions. For the final calculation, the weighted average of the rms width of all beamlets is used.

The results of two independent measurements at similar operation conditions of PITZ are summarized in Table 1. The largest uncertainty on the measured emittance comes from the noise threshold of the camera readout of the beam size and beamlet measurements. Although our CCD cameras [7] have a remote controllable gain which allows the observation of pictures with and without saturation in a large dynamic range, an industrial set noise threshold cuts the low intensity tails of distributions. The uncertainty from this effect is estimated for each beam measurement separately.

date	charge [nC] z-pos [mm] 768	charge [nC] z-pos [mm] 2736	$\|P\|$ [MeV/c]	solenoid current [A] main	solenoid current [A] buck	laser pulses N	laser pulses σ_{xy} [mm]		RMS beam size [mm]	RMS divergence [mrad]	norm. emittance [mm mrad]
Aug 29th	1.4 ±0.14	0.65 ±0.07	4.04 ±0.08	301	170	5	0.25 ±0.15	x	$0.44^{+0.14}_{-0.02}$	$0.45^{+0.09}_{-0.09}$	$1.6^{+0.6}_{-0.3}$
								y	$0.43^{+0.19}_{-0.02}$	$0.45^{+0.09}_{-0.09}$	$1.5^{+0.7}_{-0.3}$
Aug 31st	1.45 ±0.15	0.90 ±0.09	2 peaks at 4.26±0.08 3.98±0.08	300	170	1	0.25 ±0.15	x	$0.26^{+0.07}_{-0.02}$	$0.55^{+0.12}_{-0.12}$	$1.2^{+0.4}_{-0.3}$
								y	$0.25^{+0.11}_{-0.02}$	$0.64^{+0.14}_{-0.14}$	$1.3^{+0.6}_{-0.3}$

Table 1: Emittance measurements and operation parameters.

5. SUMMARY AND OUTLOOK

The photo injector test facility at DESY Zeuthen is now in operation. First measurements with and without photo electrons after several months of commissioning and running are presented.

The rf commissioning of the gun reached up to 5 Hz repetition rate with a pulse length of 400 µs and a gradient of about 34 MV/m. The maximum gradient of about 37 MV/m was measured at 100 µs pulse length and 1 Hz repetition rate.

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 FWHM. Beam charges from the pC scale up to 4.7 nC have been produced and the evolution of the beam along the beam line has been measured. The maximum electron momentum obtained was about 4.3 MeV/c. First results from the emittance measurement system have been presented. A longer program of operation and optimization 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.

6. References

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