THE PHOTO INJECTOR TEST FACILITY AT DESY ZEUTHEN: RESULTS OF THE FIRST PHASE

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Abstract

The photo injector test facility at DESY Zeuthen successfully concluded it's first phase of operation in November 2003 (PITZ1). After a complete characterization of the injector, the gun has been transfered to Hamburg and has already been taken into operation on the VUV-FEL.

The measurement program for the year 2003 included RF commissioning, emittance studies, momentum and bunch length measurements, and studies of the influence of the drive laser parameters. We provide an overview on the latest achievements in all of these topics and an outlook on the future plans at PITZ.

INTRODUCTION

The Photo Injector Test Facility at DESY Zeuthen (PITZ) has been built in order to test and optimize electron sources for Free Electron Lasers (FELs) and future linear colliders. The goal of PITZ is to produce intense electron beams with small transverse emittance and short bunch length as required for FEL operation.
The photo injector consists of a 1.5 cell L-band RF gun with a Cs_2Te photo cathode, a solenoid system for space charge compensation, a photo cathode laser system which generates long pulse trains with variable temporal and spatial pulse shape, and an extended diagnostics section. A schematics of the PITZ1 setup is shown in figure 1.

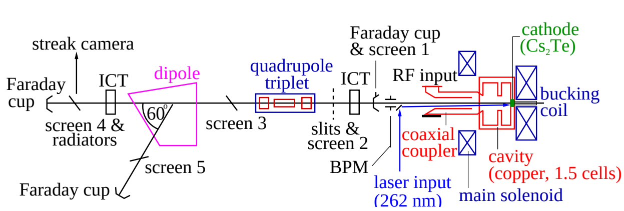

Figure 1: Scheme of the PITZ1 setup.

PITZ has been taken into operation in January 2002. The first stage of the project (PITZ1) has been successfully completed with the transfer of a completely characterized RF gun to the VUV-FEL at DESY Hamburg in November 2003. The results obtained with this gun are briefly summarized in the following section. Meanwhile, a new gun has been installed and conditioned at PITZ. Recent improvements and first measurement results as well as plans for the future of PITZ are reported below.

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RESULTS OF PITZ1

The measurement program of PITZ1 in the year 2003 included RF commissioning, emittance studies, momentum and bunch length measurements, and studies of the influence of the drive laser parameters.

RF conditioning. The smooth commissioning of the gun allowed an operation with up to 900 μs long RF pulses at 10 Hz repetition rate and about 3.3 MW peak power in the gun. This corresponds to an accelerating gradient at the cathode of about 42 MV/m, and an average power of 27 kW in the gun with 0.9% duty cycle [1]. Such a long RF pulse operation fulfills the TTF2 VUV-FEL requirements.

Photo cathode laser. The optimization of the photo cathode laser parameters included longitudinal and transverse profile. In order to minimize the space charge influence on the transverse beam emittance, a longitudinal flat top profile of 20 ps duration (FWHM) and rise/fall times of 2 ps should be realized. The transverse laser profile is needed to be radially homogeneous, and of adjustable rms size. In reality, these ideal parameters could not yet be reached. Typically, a longitudinal profile of 23 ps FWHM with 6 ps rise/fall time has been used, and a relatively homogeneous transverse profile of size $\sigma_{rms} = 0.5 ... 0.6$ mm.

Bunch charge. Detailed studies of the produced electron bunch charge as function of the RF phase and the solenoid settings were performed [1], and comparisons with simulations allowed to improve the understanding of the photo injector. The nominal bunch charge is 1 nC and can be adjusted by tuning the photo cathode laser power.

Momentum and momentum spread. Extensive measurements have been undertaken in order to study longitudinal momentum and momentum spread of the electron beam. A maximum mean momentum of 4.72 MeV/c has been measured. The minimum momentum spread was found to be 33 keV/c. For more details see [2].

Bunch length. The bunch length has been measured for different conditions [2]. A minimum length (FWHM) has been measured to be (21.04±0.45stat±4.14syst) ps.

Normalized emittance. For measurements of the normalized projected beam emittance, the slit mask scan technique is used [1]. The optimization of the photo cathode laser properties together with RF field and solenoid parameters yielded an average emittance of $\sqrt{\varepsilon_x \varepsilon_y} = 1.7\ \pi$ mm·mrad [3], see figure 2. Thus, the start-up conditions of the TTF2 VUV-FEL on normalized projected beam emittance [4] have been fulfilled.

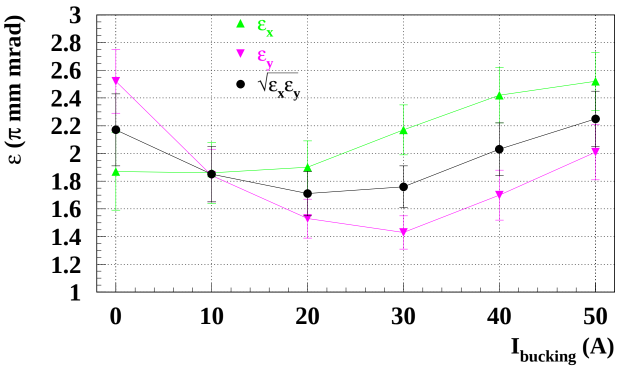

Figure 2: Measured transverse normalized emittance as function of the current in the bucking solenoid (responsible for compensating the magnetic field of the main solenoid at the cathode plane) for the optimized RF phase and main solenoid current [3]. The measurements in both planes, x and y, are shown as well as the geometric average $\sqrt{\varepsilon_x \varepsilon_y}$.

RECENT IMPROVEMENTS

After the fully characterized gun has been transfered to DESY Hamburg and taken into operation at the TTF2 VUV-FEL, a new gun cavity has been installed at PITZ. This gun has extensively been conditioned, and measurements of the electron beam properties are ongoing. The most recent measurement results comprise (see also [5]):

RF commissioning. The limited input peak power of the 5 MW klystron allows for a maximum power in the gun of about 4 MW. In order to reach a high average power, the pulse length has been increased up to 1300 μs. An average power of about 33 kW has been reached in July 2004 [5].

Dark current studies. The behaviour of the dark current emitted from the gun has been studied. Due to the high rf gradient and the limited surface quality of this gun, a high amount of dark current has been measured and was found to be the reason for destruction of vacuum components (e.g. view screens) and photo cathode surfaces [6].

Laser optical beamline. In parallel to these activities, the optical beamline of the photo cathode laser has been modified, resulting in a significant improvement of the homogeneity of the transverse laser profile at the photo cathode. Figure 3 shows an example of the laser spot at the cathode plane.

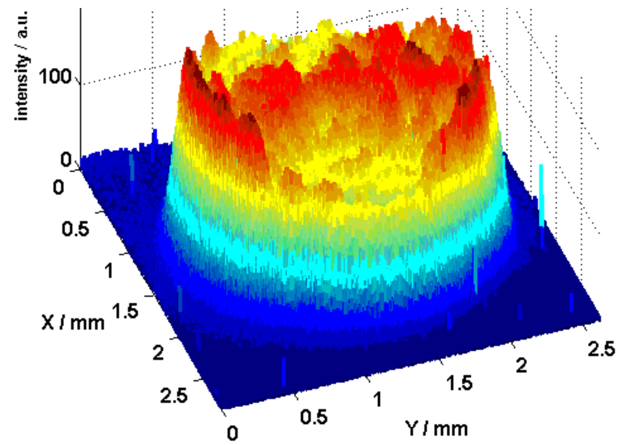

Figure 3: 3D image of the transverse laser profile at the position of the photo cathode.

Emittance measurements. Thermal emittance measurements at low charge (few pC) were performed in June 2004. An average kinetic energy of the photo electrons after emission has been found to be about 0.8 eV [3]. The normalized projected beam emittance measurements and the parameter space optimization for high gradients are ongoing. As a preliminary result, the minimum measured emittance was about 2.5 π mm·mrad at the nominal charge of 1 nC [3].

Longitudinal phase space. Momentum measurements in August 2004 resulted in a maximum momentum of 5.2 MeV/c. First measurements of the momentum spread indicated, that the minimum momentum spread could be as low as 22 keV/c, which would be considerably smaller than the PITZ1 measurements. Bunch length measurements still have to be performed.

PITZ2

The second stage of PITZ, called PITZ2, will be a large extension of the experimental setup and its measurement program [7]. The main intention is a further improvement of the electron beam quality with the goal to approach the requirements of the European XFEL. This needs an optimization of the photoinjector and all subsystems, including laser, photo cathodes, and guns, as well as simulation tools.

Booster cavity. In order to conserve the small beam emittance produced at the gun, a booster cavity will be installed. Using a preliminary booster, the beam energy will be increased from about 5 MeV to $\sim$ 16 MeV. This booster has been tuned and is presently under vacuum preparations. It will be conditioned before its installation at the beamline, which is foreseen to happen in early spring 2005. Later, the beam energy will be further increased to about 30 MeV, using a final booster specially designed for

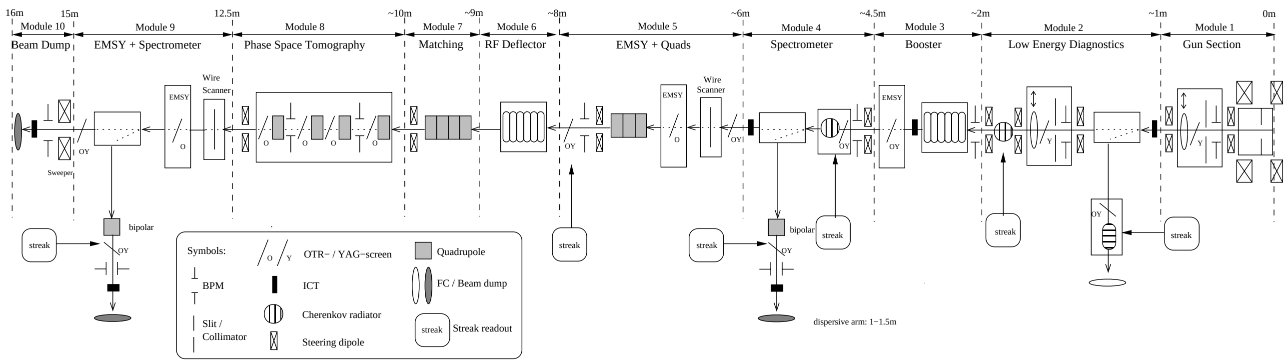

Figure 4: Preliminary layout of PITZ2.

PITZ.

RF system. In order to operate the booster cavity, a second rf system has been installed and is being taken into operation. Since reaching a higher gradient in gun and booster is essential for producing low emittance beams, the existing 5 MW klystrons will be replaced by 10 MW klystrons in the year 2005.

Beam diagnostics. The increased beam energy requires new, adapted diagnostics tools. For this reason, a completely new diagnostics beamline will be installed at PITZ, suitable for the higher beam energy. Beside standard beam diagnostics devices like e.g. OTR view screens, possibilities for slice emittance measurements and phase space tomography are foreseen to be implemented. In order to test the emittance conservation principle, the emittance development along the beam axis has to be monitored. For that purpose, three emittance measurement stations and several quadrupoles are distributed along the beamline. A preliminary layout of the complete PITZ2 beamline is shown in figure 4.

As a first step towards the PITZ2 beamline, a simplified setup with only a limited number of diagnostics devices will be realized. The design of this minimum version of the PITZ2 setup has been finished, and the beamline elements are currently under construction. Before the booster cavity can be taken into operation, a beam dump needs to be commissioned. This is a critical point, since long bunch trains and small spot sizes require special design considerations.

Laser system. The transverse and longitudinal laser profile have been found to be crucial for the production of low emittance beams. The goal is to reach the parameters determined by simulations: a longitudinal flat top distribution of 20 ps length (FWHM) with rise/fall times of 2 ps, and a very homogeneous, circular transverse laser profile. These requirements can only be realized by a special development of the laser system (a two-channel mixing system, mixing high power gaussian and low power rectangular laser pulses) and a further improvement of the optical beamline.

Further optimization. In order to reach optimum electron beam parameters and improve the theoretical understanding of the photo injector, the optimization of all subsystems is needed. For that purpose, extensive beam dynamics simulations have to be done and compared to measurements. This includes improvements on the simulation tools.

Furthermore, it is planned to improve the existing gun design and develop a gun for the European XFEL with improved geometry and cooling. This is a precondition for the exploration of the European XFEL parameter space and high duty cycle operation. For that, studies of the photo cathode materials are also necessary and foreseen.

SUMMARY

The first phase of PITZ has successfully concluded in November 2003 with the full characterization of the photo injector. The main results have been summarized. A large extension of the existing setup and the measurement program is planned. Preparations for the PITZ2 project are ongoing, and results of the first improvements have been presented.

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