NEW EXPERIMENTAL RESULTS FROM PITZ*

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Abstract

The **P**hoto **I**njector **T**est facility at DESY, **Z**euthen site, (PITZ) was built to develop and optimize high brightness electron sources for Free Electron Lasers (FELs) like FLASH and the European XFEL. Last year, an electron beam with a very low transverse projected emittance of 1.26 mm mrad for 1 nC charge (100% RMS) was demonstrated [1, 2, 3]. In the shutdown last winter, a major upgrade of the facility took place where many new diagnostics elements were installed and almost all components in the beamline were repositioned. In addition, a new RF gun cavity with improved water cooling was installed and conditioned. It is the first RF gun where the surface cleaning was done with a dry-ice technique instead of high-pressure water rinsing. It showed a 10 times lower dark current emission than its precursor gun, even at cathode gradients as high as 60 MV/m. Also a new photo cathode laser system with higher bandwidth was installed, which so far has produced Gaussian laser pulses of 2.1 ps FWHM.

This contribution will summarize the transverse emittance measurements in 2007, the upgrade of the facility, dark current measurements from the new dry-ice cleaned RF gun cavity and quantum efficiency measurements of Cs_2Te photo cathodes.

INTRODUCTION

SASE-FELs for short photon wavelengths require electron sources providing particle beams with very good beam properties. Therefore, DESY is operating and continuously extending a photo injector test facility at its Zeuthen site (PITZ). It contains an 1½ cell L-band RF gun with cathode load-lock system and solenoids for space charge compensation, a laser system able to generate trains of electron pulses including temporal and transverse laser beam shaping, a booster cavity and many beam diagnostics systems for the characterization of the electron beam at different beam energies.

In the first section of this paper measurements of very low transverse emittance are summarized. These data have been taken in summer 2007 with a facility setup that was mainly unchanged since beginning of 2006. From autumn 2007 to spring 2008 a major upgrade of the facility took place and the current setup is shortly described in the second section. During the shutdown a new RF gun cavity treated with a dry-ice surface cleaning technique was commissioned at an accelerating gradient of 60 MV/m which is reported in the third section. In the fourth section recent quantum efficiency measurements of Cs_2Te photo cathodes are presented.

EMITTANCE MEASUREMENTS FROM SUMMER 2007

The transverse normalized projected emittance is of paramount importance for electron sources driving FELs. In summer 2007 it was measured at a bunch charge of 1 nC for gun cavity prototype 3.2, which was the first RF gun operated at PITZ with about 60 MV/m maximum accelerating gradient at the cathode. This cavity was cleaned with high-pressure water rinsing. Although the level of dark current at the maximum gradient was high (see details in commissioning section) this did not have a major influence on the emittance measurements when using the single slit measurement technique at a distance of 4.3 m from the photo cathode. Details of the measurement procedure and the data analysis are described in references [1, 2, 3]. An extensive experimental scan of different machine parameters resulted in an absolute minimum of the transverse normalized projected emittance for the following conditions: The gun was operated at a maximum accelerating gradient at the cathode of about 60 MV/m. The RF phases for gun and booster where set to maximum mean momentum gain. The beam momenta were 6.44 MeV/c downstream the gun and 14.5 MeV/c downstream the booster. The Cs_2Te cathode number 90.1 was used with a laser beam of about 0.36 mm rms spot size (approximate flat-top transverse shape) and an approximately flat-top temporal distribution of about 20 ps FWHM with 6-7 ps rise/fall time. The main scan parameter is the main solenoid current. A bucking magnet is always used to zero the magnetic field on the cathode. The measurement results of two different shift crews are shown in Figure 1. The repeatability is a few percent.

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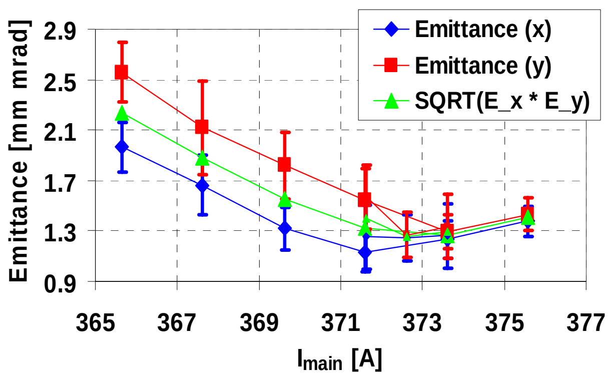

Figure 1: Transverse normalized projected emittance for different main solenoid currents at a bunch charge of 1 nC. Relevant machine parameters are given in the text. The numbers represent 100% RMS values.

The absolute emittance minimum is obtained at a main solenoid current of about 372.5 A with $\varepsilon_x = 1.25 \pm 0.19$ mm mrad in the horizontal and $\varepsilon_y = 1.27 \pm 0.18$ mm mrad in the vertical plane. Maximum effort has been performed to minimize intrinsic cuts in the particle distributions for the measurements by using highly sensitive screens, 12 bit signal resolution, large enough areas of interest to cover whole beam distributions and so on. Therefore, the numbers presented here can be considered as 100 % RMS emittance. The error bars represent the statistical fluctuation of the particle distributions during the measurements. As discussed elsewhere [3] there is an additional systematic uncertainty of the emittance numbers of about 20 %.

While the results presented above have been obtained with scanning 11 slit positions over the whole beam size additional measurements with more than 40 beamlets were performed at the point of minimum emittance found before. The horizontal phase space is shown in Figure 2.

The 100% RMS emittance is strongly dependent on the tails of the particle distributions. If for example particles below a certain phase space density in Figure 2 are removed from the analysis, then neglecting a charge fraction of only 10% will result in an emittance reduction of more than 30%, yielding 0.9 mm mrad [3]. Since these particles in the tails of the distribution will most probably not contribute to the lasing of the FEL this is considered to be the first demonstration of the beam quality required for the European XFEL.

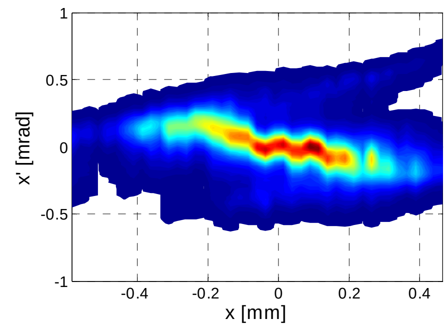

Figure 2: Detailed sampling of the horizontal phase space at the smallest emittance shown in Fig. 1 (I_{main} = 372.5 A).

UPGRADE OF THE PITZ FACILITY

At the end of August 2007 a major upgrade of the PITZ facility was started where many new diagnostics elements were installed and almost all components in the beamline were moved to new locations. The current setup is schematically shown in Figure 3. Downstream the new gun cavity (described in the next section) a new RF shielded vacuum valve and a new diagnostics cross were mounted to reduce wakefield effects and especially improve the vacuum conductivity. A new low energy dipole was installed to cure aperture problems at low main solenoid currents present before. Due to the increased maximum gun gradient of 60 MV/m, the booster cavity was moved to a larger distance from the photo cathode. Downstream the booster cavity, quadrupoles and a new, multi-purpose 180-degree spectrometer system below the main beamline were installed. Three emittance measurement systems (EMSYs) were located at the exit of the booster, the end of the beamline and in between. Also the Cherenkov radiators with streak readout for measurements of the longitudinal phase space were repositioned. In addition, a new photo cathode laser system with higher bandwidth was installed. This system has mainly produced Gaussian laser pulses of 2.1 ps FWHM up to now and with a new pulse shaper will be able to create flat-top temporal laser shapes of ~20 ps FWHM with ~2 ps rise/fall time [4]. More details on the new setup can be found in [5].

COMMISIONING OF A NEW RF GUN

In winter 2007/2008 the RF gun prototype 4.2 was commissioned at PITZ [6]. There are two major

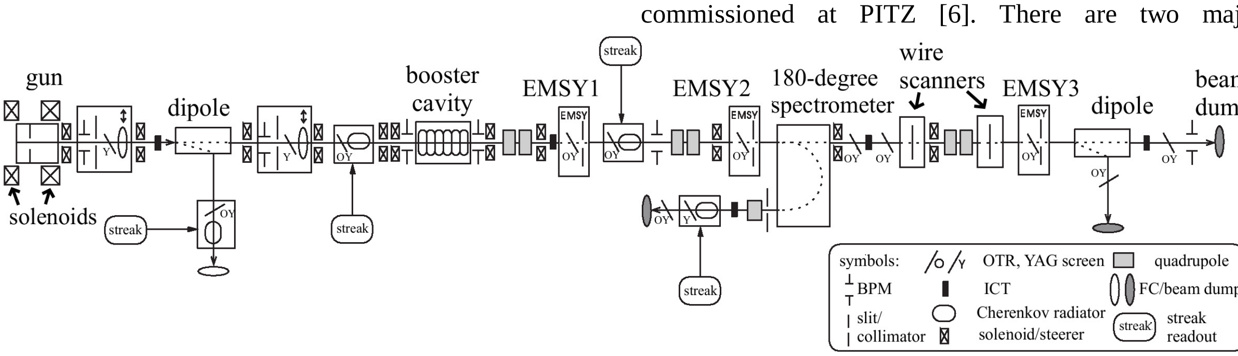

Figure 3. Layout of the upgraded photo injector test facility in Zeuthen (setup PITZ-1.7).

differences between this cavity and earlier prototypes: A) Instead of two there are now 14 independent water input channels which allow a detailed control and monitoring of the water flow rate in the different parts of the cavity cooling. B) The particle free cleaning of the inner surface of this cavity was for the first time done with CO_2 snow instead of the high-pressure water rinsing (HPWR) technique used up to now. The new dry-ice technique is effectively removing particles down to 100 nm without placing any water on the copper surface [7]. This led to a major improvement of the vacuum conditions in the gun and a major reduction of the emitted dark current by a factor of more than 10 as demonstrated in Figure 4. The dark current presented here is always the maximum dark current emitted during a main solenoid scan between 0 and 500 A for a given RF power in the gun cavity. As visible from Figure 5, the dark current in general goes further down with more conditioning time at longer RF pulse length and there is no major difference between pure molybdenum cathodes and those with Cs_2Te coating. In addition, Figure 5 demonstrates that gun prototype 4.2 has been operated with more than 7 MW at 700 μs flat-top RF pulse length. Since the repetition rate was 10 Hz and the RF fill time was set to 32 μs, the average RF power stored in the gun was more than 50 kW.

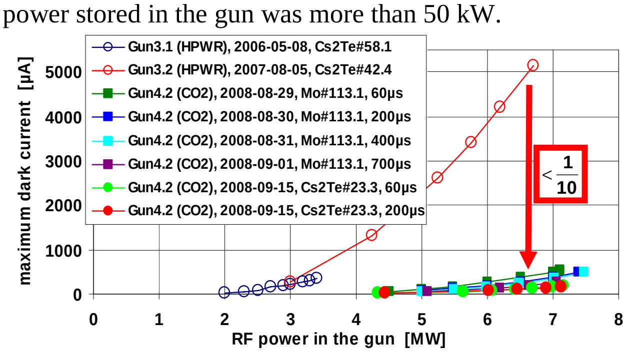

Figure 4: Maximum dark current for different gun cavities treated with different cleaning techniques.

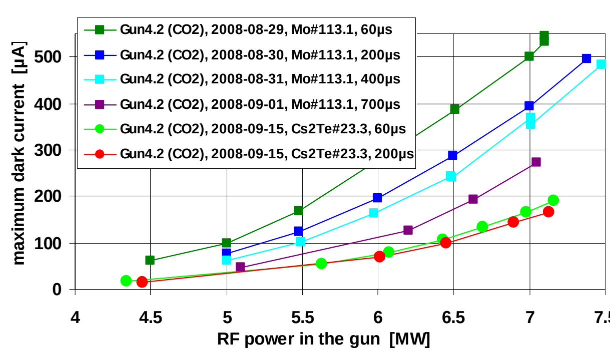

Figure 5: Maximum dark current for different RF pulse lengths and cathodes, ordered in sequence of data taking.

QUANTUM EFFICIENCY

The quantum efficiency is regularly measured at PITZ. Figure 6 shows different measurements as a function of the accelerating field during electron emission. The full line represents a fit including a Schottky-like model for lowering the work function by the electric field.

Figure 7 shows the transverse distribution of the QE over the cathode surface. The scan was done with an RMS laser spot size of about 0.18 mm. The QE homogeneity in the central part is better than ±10 % which is within the measurement accuracy.

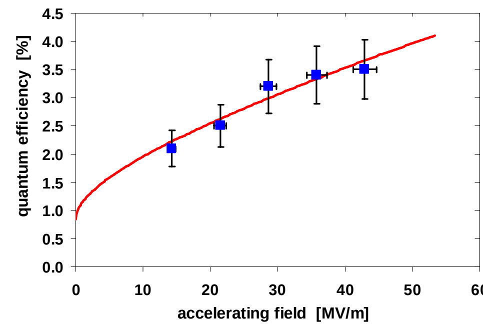

Figure 6: Quantum efficiency of Cs_2Te cathode #23.3 as a function of the accelerating field at the photo cathode.

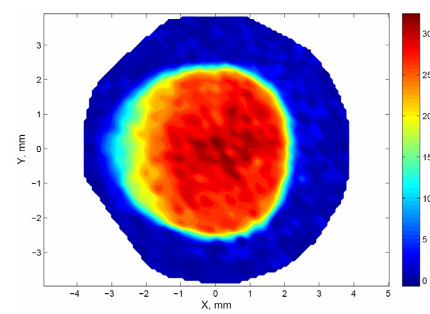

Figure 7: Quantum efficiency map of Cs_2Te cathode #23.3. The colour code gives relative information only.

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