RECENT DEVELOPMENTS at PITZ*

M. Krasilnikov†, K Abrahamyan, G. Asova, J. Bähr, G. Dimitrov, U. Gensch, H.-J. Grabosch, J.H. Han, S. Khodyachykh, S. Liu, V. Miltchev, A. Oppelt, B. Petrosyan, S. Riemann, L. Staykov, F. Stephan, DESY, 15738 Zeuthen, Germany
M.v. Hartrott, E. Jaeschke, D. Kramer, D. Lipka, D. Richter, BESSY GmbH, 12489 Berlin, Germany
J.-P. Carneiro‡, K. Flöttmann, S. Schreiber, DESY, 22603 Hamburg, Germany
J. Rönsch, J. Rossbach, Hamburg University, 22761 Hamburg, Germany
P. Michelato, L. Monaco, C. Pagani, D. Sertore, INFN/LASA, 20090 Segrate, Italy
I. Tsakov, INRNE, 1784 Sofia, Bulgaria
W. Sandner, I. Will, MBI, 12489 Berlin, Germany
W. Ackermann, W. F.O. Müller, S. Schnepp, T. Weiland, TU-Darmstadt, 64289 Darmstadt, Germany

Abstract

The ability to produce high brightness electron beams as required for modern Free Electron Lasers (FELs) has been demonstrated during the first stage of the Photo Injector Test Facility at DESY Zeuthen (PITZ1). The electron source optimization at PITZ1 was successfully completed, resulting in the installation of the PITZ rf gun at the VUV-FEL (DESY, Hamburg). One of the main goals of the second stage of PITZ (PITZ2) is to apply higher gradients in the rf gun cavity in order to obtain smaller beam emittance by faster acceleration of the space charge dominated beams. In order to reach the required gradients a 10 MW klystron has to be installed and the gun cavity has to be conditioned for higher peak power. Another important goal of PITZ2 is a detailed study of the emittance conservation principle by using proper electron beam acceleration with a booster. Further photo injector optimization, including update of the photocathode laser and diagnostic tools, is foreseen as well. Recent progress on the PITZ developments will be reported.

INTRODUCTION

The possibility to achieve small beam emittances in a photo injector has been demonstrated at PITZ1 [1, 2]. Many rf gun parameters have to be optimized to obtain high performance of the electron source. In order to suppress a space charge induced emittance growth a fast beam acceleration should be provided by applying high rf gun gradients (E_{cath}). Simulations for the PITZ2 setup show that a minimum emittance can be decreased from 1.26 mm mrad for $E_{cath} = 42\ MV/m$ to 0.87 mm mrad for $E_{cath} = 60\ MV/m$. Nevertheless, the space charge blows up the emittance after the rf gun. To prevent this emittance growth a booster cavity has to be used. Simulations for the PITZ2 setup with preliminary booster show that under proper matching conditions the emittance can be conserved and damped: for $E_{cath} = 42\ MV/m$ from 1.26 mm mrad to 1.09 mm mrad and for $E_{cath} = 60\ MV/m$ from 0.87 mm mrad to 0.84 mm mrad.

The photocathode laser beam parameters play a central role in obtaining small emittances. A major upgrade of the photocathode laser system at PITZ includes a replacement of the flash lamps with diode-pumped amplifiers, improving stability and reliability of the laser performance. Further developments on the laser beam line result in improved laser beam transverse shape.

Higher beam energies require an update of the electron beam diagnostic tools. The slit mask technique used at PITZ for the emittance measurement has to be adapted to the upgraded facility. First measurements of the longitudinal phase space have been performed in the low energetic section of PITZ.

TOWARDS HIGHER RF GUN GRADIENTS

Up to now, rf gun gradients at about 45 MV/m have been reached at PITZ. This is at the limit of the power, which is delivered from the 5 MW klystron. To reach rf gun gradients of 60 MV/m, a 10 MW multi beam klystron (MBK) must be installed at PITZ. A first MBK was installed in January 2005 but showed severe technical problems during the commissioning. A replacement klystron will be delivered in May 2005.

Beam dynamics simulations with ASTRA [3] have been performed for the PITZ2 setup (Fig. 1a) optimizing the main photo injector parameters for different rf gun gradients (Tab. 1). The longitudinal position of the booster ($z \approx 2.5\ m$) corresponds to the layout of the VUV-FEL photo injector [4]. The simulated emittance for a 1 nC beam along the PITZ2 beamline is shown in Fig. 1. The photocathode laser was assumed to have a flat-top temporal profile with 20 ps FWHM and 2 ps rise/fall time and radially homogeneous transverse distribution with varied radius. Thermal emittance was taken into account by assuming a thermal kinetic energy of the photo electrons emitted from the Cs_2Te cathode to be 0.55 eV.

* This work has partly been supported by the European Community, Contract Number RII3-CT-2004-506008, and by the 'Impuls- und Vernetzungsfonds' of the Helmholtz Association, contract number VH-FZ-005.

† mikhail.krasilnikov@desy.de
‡ now at FNAL

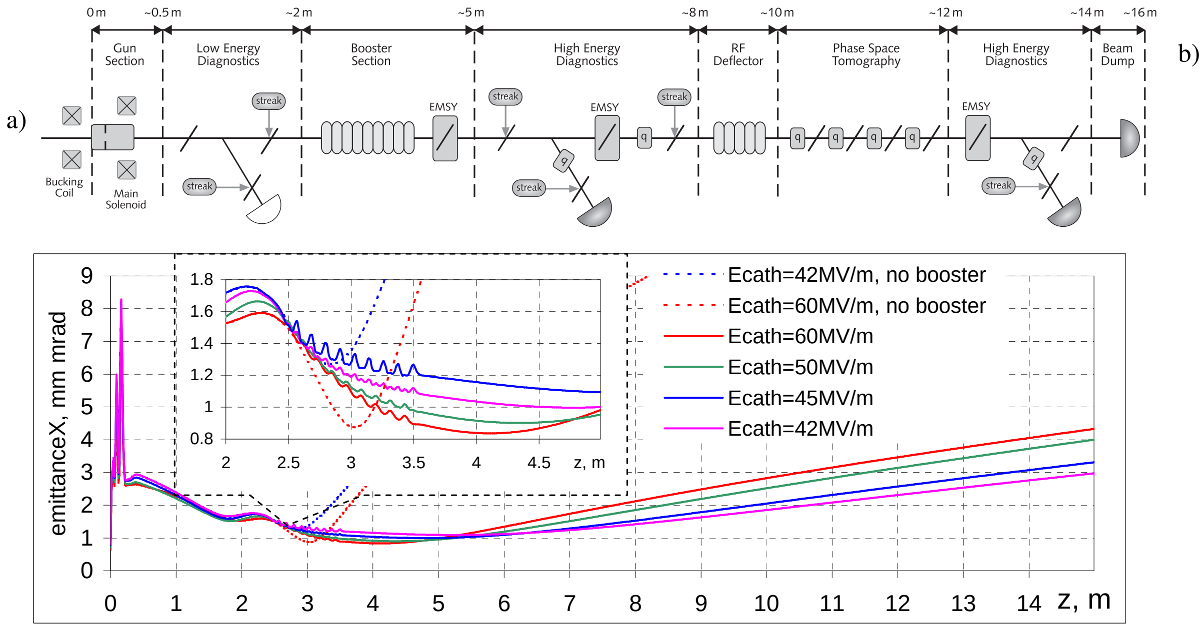

Figure 1: a) PITZ2 setup. b) Simulated emittance along the PITZ2 beamline optimized for different rf gun gradients.

Table 1: Optimized photo injector parameters (simulations, 1 nC bunch charge)

rf gun	E_{cath}, MV/m φ, deg	42 -2.1	45 -2.0	50 -1.9	60 -1.9
solenoid	$B_{z,peak}$, mT	-166.8	-177.0	-193.9	-227.7
cathode laser	XY_{rms}, mm	0.69	0.67	0.61	0.56
booster	$E_{z,max}$, MV/m φ, deg	26.3 -13.6	25.4 -15.6	23.4 -16.1	26.0 -15.1
emittance	min $\varepsilon_{x,y}$, mm mrad	1.09	1.00	0.90	0.84

UPGRADE OF THE CATHODE LASER

The photocathode laser was significantly improved. All flash lamp-pumped booster amplifiers were replaced by diode-pumped stages, so that the laser is now completely pumped by semiconductor diodes. This simplifies maintenance and improves stability and reliability. Since diode pumping reduces heat load in the booster amplifiers, the laser can now run at 10 Hz at its nominal power level. To adjust the energy of the UV pulses a simple attenuator (throttle) is used, which simplifies operation. The laser contains the following consequent building blocks: pulse-train oscillator → grating pulse shaper → four-stage preamplifier → two-stage booster → wavelength conversion crystals → UV attenuator. The laser beamline at PITZ is used to image the laser beam from the conversion crystals via a beam shaping aperture (BSA) to the photocathode over a distance of 27 m. Thereby, the main goal is to produce a laser spot on the cathode having a flat-top transverse profile. In the first months of 2005 a new optical scheme with improved technical realization was commissioned. The principle consists on an improved imaging of the BSA onto the photocathode over a decreased distance between BSA and cathode. The BSA is illuminated by imaging the conversion crystals to the BSA (different apertures can be chosen and adjusted in 3 dimensions remotely). Several remotely controlled optical elements are used to steer the laser beam over the cathode in 4 degrees of freedom. A pinhole is used for spatial filtering in the frequency domain. A CCD-camera sensitive in the UV region allows to monitor the transverse distribution of the laser beam in a plane corresponding to the cathode plane. A further branch created by a beam splitter will allow the monitoring of the relative laser beam energy in all pulses of a pulse train using a photomultiplier.

BOOSTER CAVITY CONDITIONING

As it can be seen from Fig. 1b, a small emittance can be conserved and damped by applying a booster cavity under proper matching conditions. The PITZ2 preliminary booster is a normal conducting copper resonator, which has been constructed in 1992 as a prototype for the sc TESLA cavities. Since the cavity has been stored in air for a long time, the cleaning was done very thoroughly. Afterwards the cavity has been tuned [5], resulting in a tolerable field flatness (Fig. 2). The booster cavity is now under conditioning at PITZ and an average rf gradient of 12 MV/m needed for the emittance conservation principle study has already been achieved.

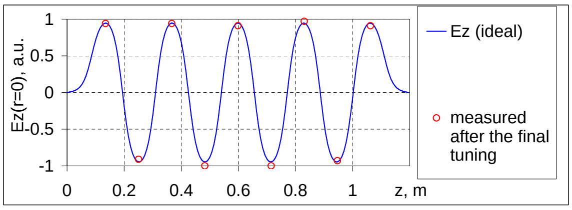

Figure 2: Field distribution on the axis of the booster cavity. Field amplitudes in cells measured after the final tuning shown with circles.

UPGRADE OF THE DIAGNOSTICS

The system for measuring the transverse electron beam emittance for the second phase of PITZ was optimized to measure emittances below 1 mm mrad in the beam energy range 5-30 MeV. The emittance will be measured using a slit technique which means that the uncorrelated RMS divergence of the beam will be determined from the beamlets produced by a slit mask. YAG and OTR screens will be used to measure the transverse beam profile. The emittance measurement system consists of two orthogonal actuators on which the screens and the slit masks will be mounted. The masks will be made from 1 mm thick tungsten and the slit opening will be 10 μm. The drift length for the beamlets is designed to be not smaller than 1 m to obtain a reasonable resolution and a good signal-to-noise ratio. The system is under construction at INRNE Sofia, installation of the system and first measurements are expected in the autumn 2005.

First measurements of the longitudinal phase space using Cherenkov radiators (silica aerogel) [6] in the straight and dispersive arms at the low energy section at PITZ have been performed. An electron bunch is transformed into a light pulse with similar spatial and temporal distribution. It is imaged onto the entrance slit of the streak camera by an optical transmission line [7]. The longitudinal phase space was measured for different temporal laser distributions, bunch charges and rf launch phases. Physical effects in the dipole, optical transmission line and streak camera, which influence the longitudinal phase space measurements are taken into account. The measurement results were compared with ASTRA simulations and with directly measured momentum and temporal distributions (see Tab. 2). Between the projections of the measured longitudinal phase space, direct measurements of momentum distribution and longitudinal distribution and simulations a good agreement can be achieved. In general the shape of the measured and simulated longitudinal phase space are comparable, but for smaller bunch charge the measured longitudinal phase space is broadened and therefore the measured values of the longitudinal emittance are higher than the simulated one.

Table 2: Measurements of the longitudinal phase space, 1 nC bunch charge, flat-top temporal laser profile, rf phase of maximum energy gain.

	measurements of the projections	longitudinal phase space	ASTRA simulation
t_{FWHM}, ps t_{rms}, ps	25.2 ± 1.3	29.5 ± 2.0 6.42 ± 0.83	24.99 7.91
$< p >$, MeV p_{rms}, keV	5.19 ± 0.06 46.0 ± 5.1		5.19 42.2
ε_z, mm keV		32.7 ± 6.8	26.55

CONCLUSIONS

As demonstrated by simulations the emittance needed for FEL projects like the European XFEL can be obtained by increasing the rf gun gradient to 60 MV/m and applying a proper matching with a subsequent booster cavity. For increasing the rf gun gradient above 45 MV/m at PITZ, a 10 MW multi beam klystron must be commissioned, what is foreseen to take place in summer 2005. A preliminary version of the booster cavity has already been conditioned up to the required gradient.

An upgraded cathode laser system based on completely diode-pumped amplifiers together with an improved laser beamline was installed and is expected to demonstrate higher performance, stability and reliability.

Longitudinal phase space measurements at a beam energy around 5 MeV have been demonstrated. Further developments on beam instrumentation downstream of the booster cavity are ongoing.

REFERENCES

[1] M. Krasilnikov et al., "Optimizing the PITZ electron source for the VUV-FEL",EPAC'04, July 2004, Lucerne, pp. 360-362.

[2] F. Stephan et al. "Recent results and perspectives of the low emittance photo injector at PITZ", FEL'04, August-September 2004, Trieste, pp. 347-350.

[3] K. Floetmann, A Space Charge Tracking Algorithm(ASTRA), http://www.desy.de/ mpyflo/.

[4] "SASE FEL at the TESLA Facility, Phase 2", DESY TESLA-FEL-2002-01.

[5] A. Oppelt, F. Tonisch, "Tuning of the TESLA booster", PITZ Note 532.

[6] J. Bähr et al., "Silica aerogel radiators for bunch length measurements", NIM A 538 (2005) pp. 597-607.

[7] J. Bähr et al., "Optical transmission line for streak camera measurement at PITZ", Dipac Mainz 2003, pp. 98-100.