

STATUS AND PERSPECTIVES OF THE PITZ FACILITY UPGRADE*

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Abstract

The Photo Injector Test facility at DESY in Zeuthen (PITZ) has been established to develop and optimize electron sources that cover requirements of Free Electron Lasers (FELs) facilities such as FLASH and the European X-ray Free Electron Lasers (XFEL). A major upgrade of the facility is ongoing in steps, in parallel to the commissioning of the extended setup and first experiments. The new setup towards the final design mainly includes a photo cathode RF gun, a post acceleration booster cavity and several diagnostic systems. In order to fulfill the characterization of the high brightness electron source, the diagnostic systems will consist of three emittance measurement systems, two high-energy dispersive arms, an RF deflecting cavity and a phase space tomography module as well as bunch length diagnostics. In this paper, results of the commissioning of the new RF gun, which has been installed and conditioned at PITZ in spring and summer of 2007, the current PITZ status and details of the future facility upgrade will be presented.

INTRODUCTION

Source and injector development has been realized as one of the most important challenges in electron accelerator technology since several accelerators, e.g. FELs, XFEL or Linear Collider, demand excellent beam conditions right from the source. The main requirement for an electron injector is its capability to produce a high brightness beams. PITZ has been designed and built to serve this purpose in order to produce intense electron beams with very small transverse emittance and reasonably small longitudinal emittance. The main objective at PITZ is to generate a reliable electron beam, with transverse emittance of

about 1 mm mrad with a bunch charge of 1 nC and an energy spread smaller than 1%. The possibility to achieve small beam emittance has been demonstrated during the successful commissioning of the facility in the first phase (PITZ1) [1] and intermediate upgraded phase (PITZ1.5) [2].

Further upgrade of the facility towards the final design PITZ2 has been continued to extend the ability to achieve a smaller beam emittance. The so called PITZ1.6 has been finalized and was taken into operation in 2006. PITZ1.6 has completed its tasks with characterization of two new gun cavities (prototype 3.1 and 3.2). Recent commissioning and experimental results from PITZ1.6 with gun 3.2 will be discussed in this paper. Furthermore, the facility upgrade towards the next phases will be described.

PITZ1.6 SETUP WITH RF GUN PROTOTYPE 3.2

The current PITZ setup (PITZ1.6) consists of a 1.5 cell normal conducting RF gun with a Cs₂Te photocathode and a Nd:YLF laser system, a normal conducting booster cavity for post acceleration and diagnostic systems upstream and downstream of the booster cavity. The RF gun and booster cavity are operated with separated L-band (1.3 GHz) RF power systems. The diagnostic sections include devices for characterize the electron beam, e.g. beam size, bunch charge, its position, transverse emittance, longitudinal phase space distribution, electron bunch length, beam momentum and momentum spread. The main upgrade from PITZ1.5 to PITZ1.6 comprises installation of three new emittance measurement systems [3] and a new screen station after the booster for bunch length measurements at electron energies between 4 and 40 MeV [4]. Gun prototype 3.1 was installed and operated up to the maximum requirements of FLASH with maximum peak power of 3.5 MW, resulting in ~40 MV/m gun gradient at the cathode, with RF pulse length of 900 μ s at 10 Hz repetition rate [5]. Gun prototype 3.2 was installed in the PITZ1.6 beam line and was taken into operation in April 2006. A main goal for its operation is to study and optimize its properties in the presence of a high accelerating gradient of up to 60 MV/m.

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Tuning of Gun 3.2

In October 2006, frequency measurements of the gun cavity have been performed and the results showed a detuning from 1.3 GHz of 746 kHz at an expected operation temperature of 55°C. The field profile of the gun 3.2 cavity was measured by using the bead-pull technique and the field at the cathode was about 18% higher than in the full cell. Since a preferable value of the field balance from simulation in order to compromise between high momentum gain and a maximum gradient at the cathode for space charge compensation is about 5-10%, the gun was mechanically tuned by using a convenient tuning device to slightly deform the cavity walls at the cathode plat and at the coupler-facing wall of the iris [5].

The gun was tuned to reach a desired resonant frequency of 1.3 GHz at an operating temperature of 56°C with the field balance between the half and the full cell of 1.03 or the field at the cathode is 3% higher than that in the middle of the full cell. The field distribution before and after the tuning are shown in Fig. 1. Prior to installation at PITZ, water-to-air leak of a cooling channel was found. After the leak was repaired, the frequencies and the quality factor of the gun were re-measured resulted in a higher frequency corresponding to an operating temperature of 64°C. Field profile was not re-measured. RF measurement results of gun 3.2 before and after the tuning process as well as when it was installed at PITZ are summarized in Table 1. The quantities f_π , $Q_{0\pi}$ and $f_{\pi-0}$ stand for the resonant frequency, the unloaded quality factor of π -mode and the mode separation between π - and 0-mode, respectively.

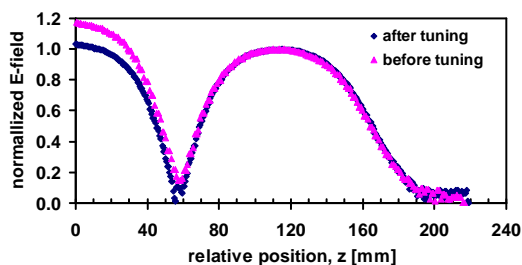


Figure 1: Electric field profile in Gun 3.2 cavity before and after tuning process.

parameter	before	after	at PITZ
f_π [GHz]	1.3013	1.3003	1.3007
$f_{\pi-0}$ [MHz]	5.0	5.1	5.0
$Q_{0\pi}$	-	21316	23853

Table 1: RF measurement results of Gun 3.2 before tuning, after tuning and after installation at PITZ.

Conditioning and Dark current Measurements

After the brazing, the tuning and the cleaning process finished, the gun has been installed and commissioned at FEL Technology I

PITZ from April to August 2007. It has been conditioned up to a maximum gun gradient of about 60 MV/m at maximum power of 6.9 MW and the stable operation can be achieved with the RF pulse length up to 200 μ s. Further, the RF pulse length was increased to 700 μ s but only for the short time period because of high level of dark current. Then, the gun cavity conditioning has been continued at RF pulse length of 400 μ s for about two weeks before the nominal experiments started. History of the gun gradient and RF pulse length during the conditioning (April-June 2007) is shown in Fig.2. In nominal experiments, the gun has been operated mostly for RF pulses of 140 μ s (with 100 μ s flat-top) at 10 Hz repetition rate. The nominal peak power in the gun cavity was 6.7 MW corresponding to the average power of 9.4 kW for 140 μ s RF pulses.

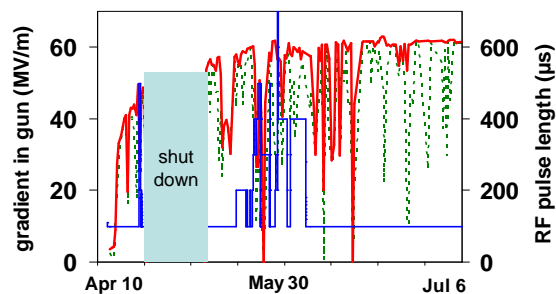


Figure 2: Gun gradient and RF pulse length history of gun 3.2 at PITZ. Maximum gradient (red line) is the highest gradient reached in the cavity, average gradient (green dot) is the average accelerating gradient over operating time period of one hour and the RF pulse length is represented by the blue line.

Cesium telluride (Cs_2Te) photo cathodes are used at PITZ for standard operation, whereas molybdenum (Mo) cathodes have been applied for the conditioning. Dark current measurements have been performed at various gun powers with different cathodes for both Mo and Cs_2Te types. The results are shown in Fig.3, where the maximum dark current is the highest current value measured as a function of the main solenoid currents. One of the measurements is shown in Fig.4 for Cs_2Te cathode no. 109.1. From Fig.3, one can see that the dark current level was improved from conditioning and operation for both Mo and Cs_2Te cathodes except the Mo cathode no. 32.2, which was used at the beginning of the conditioning and a serious damage on its surface has been observed. Another remarkable observation for the Mo electro-polished cathode (no. 55.3) demonstrated lower level of the dark current. These dark current measurements show the progress of conditioning, but the overall dark current level was still high.

Possible reasons may be because of the fabrication error of the area around the cathode plug during the assembling, the bad vacuum condition due the several dismounts (3 times) of the coupler which had vacuum leak after the bake out or the bad condition of the cathode after experiencing high accelerating field. Presumably, the high level of the

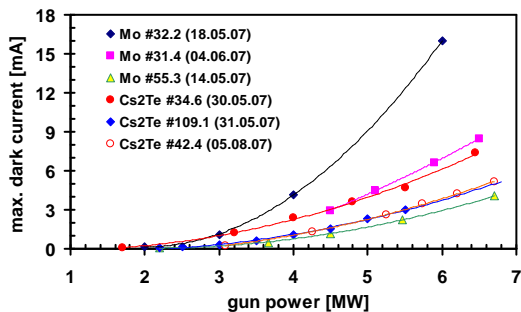


Figure 3: Maximum dark current as a function of gun power for different cathodes of gun 3.2.

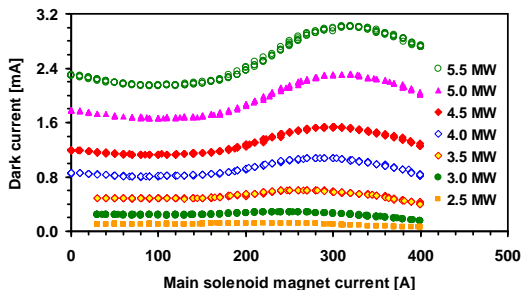


Figure 4: Dark current measurements as a function of the main solenoid magnet current for cathode no.109.1 performing on May 31, 2007.

dark current is responsible for the measured outgassing rate of some parts in double diagnostics cross (DDC, at ~ 0.78 m from the photo cathode). Several Teflon parts were found melted during DDC reparation, what explains bad vacuum conditions also in the gun cavity. Moreover, this high dark current has caused a severe radiation level in the accelerator tunnel which damaged several electronic components in the radiation effecting area. More details of the conditioning of gun 3.2 at PITZ and effects of high dark current level to delay the commissioning and experiment at PITZ are described in the reference [6].

Recent Experimental Results

Momentum and longitudinal phase space have been measured at two locations: low energy (LEDA) and high energy dispersive arms (HEDA). Experimental results show that the highest momentum value achieved from gun 3.2 was ~ 6.5 MeV/c with an energy spread of about 40 keV/c at gun power of 6.7 MW [9]. This momentum value is lower than the expectation from simulation for the gun gradient of 60 MV/m, which should be about 6.92 MeV/m for the field balance of 1.03. For the post acceleration measurement, the highest momentum measured at HEDA was ~ 16 MeV/c with 30 keV/c momentum spread. In fact, the booster can be operated with higher acceleration, but due to a limitation of the dipole current it was not possible to measure the momentum higher than 16 MeV/c.

Projected emittance measurements for gun 3.2 have been

performed using the slit mask technique at the emittance measurement station (EMSY1) located ~ 0.7 m downstream of the booster exit. The results show that the minimum transverse emittance measured during the commissioning period of gun 3.2 was 1.54 ± 0.15 mm mrad for the gun gradient of 40 MV/m and 1.26 ± 0.18 mm mrad for ~ 60 MV/m [10]. Moreover, thermal emittance from the cathode has been investigated and the results reveal that photoelectrons with kinetic energies of 1.4 ± 0.2 eV were emitted from the cathode at the gun gradient ~ 60 MV/m [11]. This value is a factor of two larger than the theoretical model.

FUTURE STAGES AT PITZ

Upgrade to PITZ1.7

In mid of August 2007, an upgrade to the intermediate phase PITZ1.7 was started. Main upgrades from PITZ1.6 to PITZ1.7 comprise a modification of the low energy diagnostics section and installation of a new high energy dispersive arm (HEDA1).

- Upgrade of low energy diagnostics section

The dipole at the present low energy dispersive arm (LEDA) at PITZ is a copy of the former injector section at FLASH which was not optimized for PITZ. The solenoid currents necessary for good focusing of the beam downstream of the booster cavity lead to the too large beam size at the dipole chamber. Modification of the pole shoes and vacuum chamber will be performed to increase the vacuum chamber aperture from 12mm to 27mm. In addition, the double diagnostic cross (DDC) in front of the dipole will be upgraded in order to improve the situation of vacuum and wake fields. The new DDC will include a slit which will be used to improve the resolution of the momentum measurements at LEDA.

- The first high energy dispersive arm (HEDA1)

HEDA1 is designed to be a multipurpose system. It will be used as spectrometer to measure momentum, a device to characterize the longitudinal phase space and a system to measure transverse slice emittance. This system includes a 180° dipole magnet which simplify the reconstruction of the momentum measurement, a slit at the exit of the dipole, a quadrupole magnet and two screen stations. One station will be used for momentum measurements for electron energies up to 40 MeV and the other one, equipped with an optical read-out for streak camera, to investigate longitudinal phase space by using off crest acceleration in the booster and the slit exit of the dipole. HEDA1 can be used to measure the transverse slice emittance at difference longitudinal positions along the bunch.

Upgrade to PITZ2

In order to fulfill the characterization of high brightness electron beam, new diagnostic systems will be in-

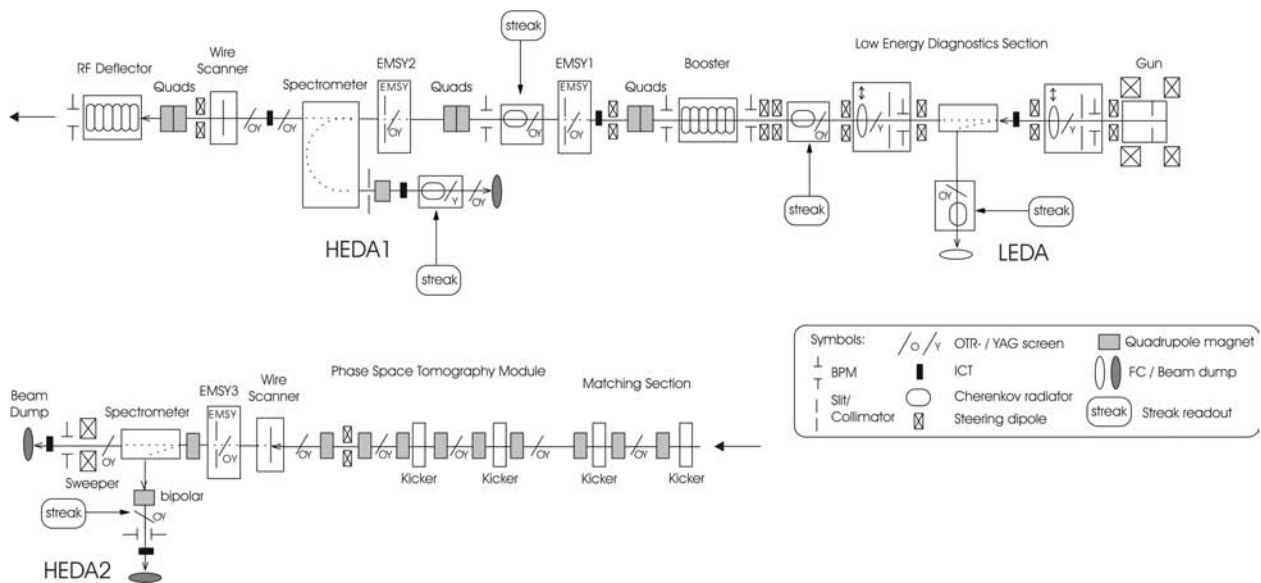


Figure 5: Schematic layout of the future PITZ2 beam line.

stalled at PITZ towards the final design (PITZ2). The PITZ2 setup includes a photocathode RF gun, a post acceleration booster cavity and several diagnostic systems including three emittance measurement systems, two high-energy dispersive arms, an RF deflecting cavity and a phase space tomography module as well as bunch length diagnostics (see Fig.5). The primary goal of PITZ2 is to study the conservation of small emittance beams along the beam line after the booster acceleration. The key parameters for this emittance conservation is the replacement of an existing TESLA booster cavity with a new Cut Disk Structure (CDS) booster, which can provide higher energy gain up to ~ 24 MeV with the limited RF power and does not degrade the beam quality. An improvement of the laser system is required in order to provide rise/fall time of 2 ps laser pulses with FWHM of 20 ps. Furthermore, additional new diagnostics will be installed in the high energy section downstream of the booster to extend the ability of facility to study more details about the beam properties. An RF deflecting cavity and a phase space tomography module will be included for analysis of the phase space distribution. At the end of the beam line, a third spectrometer will be installed in combination with diagnostics to measure momentum and momentum spread, slice emittance and longitudinal phase space using a Cherenkov radiator and streak camera or the RF-deflector. More details about the beam diagnostics upgrade for PITZ2 can be found in reference [8].

CONCLUSION

The gun 3.2 has been conditioned and taken into operation at PITZ for roughly 4 months in spring and summer of 2007. It has fulfilled the goal to operate at a gun gradient of ~ 60 MV/m with $140 \mu\text{s}$ RF pulses length and 10 Hz

repetition rate. Several results from the conditioning and experiments of this RF gun with the present PITZ1.6 beam line have been presented in this paper. Further upgrade of the facility to the next phase PITZ1.7 has started in mid of August 2007. After the upgrade is finished next operation period will start in winter 2007/2008.

REFERENCES

- [1] F. Stephan et al., "Recent Results and Perspective of the Low Emittance Photo Injector at PITZ", FEL 2004, Trieste, Italy.
- [2] A. Oppelt et al., "Status and First Results from the Upgraded PITZ Facility", FEL 2005, Stanford, CA, USA.
- [3] L. Staykov, "Commissioning of a New Emittance Measurement System at PITZ", FEL 2006, Berlin, Germany.
- [4] J. Rönsch et al., "Investigations of the Longitudinal Beam Properties at the Photoinjector Test Facility in Zeuthen", FEL 2006, Berlin, Germany, 2006.
- [5] A. Oppelt et al., "Tuning, Conditioning, and Dark Current Measurements of a New Gun Cavity at PITZ", FEL 2006, Berlin, Germany.
- [6] S. Lederer et al., "Conditioning of a new gun cavity towards 60 MV/m at PITZ", PAC 2007, Albuquerque, NM, USA.
- [7] K. Flöttmann, A Space Charge Tracking Algorithm (ASTRA), <http://www.desy.de/mpyflo>.
- [8] S. Khodyachykh et al., "New Beam Diagnostic Developments at the Photo-injector Test Facility PITZ", PAC 2007, Albuquerque, NM, USA.
- [9] J. Rönsch et al. "Recent Measurements of the Longitudinal Phase Space at PITZ", FEL 2007, Novosibirsk, Russia.
- [10] L. Staykov et al. "Measurements of the projected normalized transverse emittance at PITZ", FEL 2007, Novosibirsk, Russia.
- [11] S. Lederer et al. "Investigation on the Thermal Emittance of Cs₂Te Photocathode at PITZ", FEL 2007, Novosibirsk, Russia.