PITZ STATUS, RECENT MEASUREMENTS AND TESTS

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Abstract

The Photo Injector Test facility at DESY, Zeuthen site (PITZ) is dedicated to the development and optimization of a high-brightness electron source for the European XFEL. Recently a significant upgrade has been done at the facility. A new RF system has been installed for the PITZ gun, enabling higher attainable peak power in the cavity which is important for efficient LLRF regulation. First long-term tests for a stable gun operation at high duty cycle have been performed. Two major components for electron beam diagnostics – a transverse deflecting cavity for time resolved electron bunch characterization, and a second high energy dispersive arm for precise longitudinal phase space measurements – have been installed. First results of their commissioning will be reported.

INTRODUCTION

The PITZ facility develops and tests high-brightness electron sources for free-electron lasers, such as FLASH and the European XFEL in Hamburg. The current PITZ setup consists of a photo cathode rf gun, a normal conducting booster cavity and various systems for electron beam diagnostics. The photo cathode laser system is developed and supported by the Max-Born-Institute (MBI, Berlin). One of the major goals of the facility is to minimize the projected normalized emittance for electron beams with different charges. The projected emittance for bunch charges in the range between 20 pC and 2 nC was minimized by multi parametric machine tuning, setting a new benchmark for high-brightness photo injector performance [1, 2]. The challenging time structure of the electron pulse train is one of the important specifications to be demonstrated at PITZ. The photo injector is capable to produce trains with up to 800 micro pulses and 1 μs spacing between the pulses of the train at 10 Hz repetition rate. Demonstration of stable electron beam production supporting the maximum available duty factor is a subject of the so-called long-term tests (LTTs), which were performed at PITZ in 2012.

Being a spare gun for the FLASH user facility, the PITZ gun in May 2012 has replaced the FLASH gun, which was damaged during operation. The installation of a spare gun cavity for PITZ (the gun prototype 3.1) is under preparation. Dry ice cleaning of which is supposed to reduce the field emission significantly has been applied to this cavity.

In parallel, a number of important upgrades have been carried out at PITZ to improve the electron beam diagnostics, namely to characterise the bunch slice properties. The transverse deflecting system (TDS) was built to characterize the temporal properties of electron bunches from the photo injector. The deflecting cavity was developed at the Institute for Nuclear Research (INR, Moscow, Russia) and is planned to be also applied at the European XFEL. A prototype of the system will be tested at PITZ; the final installations are ongoing. Another important diagnostic device recently installed and commissioned is the second high energy dispersive section in the PITZ linac. Besides the beam momentum measurements it can be used for single shot measurements of the longitudinal phase space and the slice energy spread when used together with the TDS cavity.

RF GUN

The PITZ gun is a 1.6 cell normal conducting rf cavity with a Cs_2Te photocathode. It is operated at 1.3 GHz with a maximum rf peak power of ~6 MW in the cavity. The gun cavity is fed using a 10 MW multi-beam klystron with two outputs, the mean length of each waveguide arm is about 40 m. A major part of the waveguides is filled with SF_6 in order to reduce the spark rate. A vacuum T-combiner is located in the gun cavity vicinity isolated from the SF_6-filled waveguide line by two ceramic rf windows. The T-combiner is followed by a 10 MW in-vacuum directional coupler; the feed-forward and the feedback are realized based on signals from the two antennas of the directional coupler. The rf gun cavity operated at the maximum peak power delivers electron bunches with maximum mean momentum of ~7 MeV/c.

The gun cavity (gun prototype 4.1) was conditioned with rf pulses up to 700 μs duration applying the full available peak power, but for emittance optimization [3, 4] a maximum rf pulse duration of 300 μs was used. In order to check the gun trip rate at the full average power performance long-term tests were carried out in 2012 at PITZ. Results of these tests are discussed below.

PITZ rf guns also serve as spare guns for the running FEL user facility FLASH in Hamburg. In May 2012 the rf gun at FLASH (gun prototype 4.2 being also commissioned and characterized at PITZ in 2008-2009 [2]) has shown significant problems during operation at an rf peak power level of ~4 MW, including

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increased dark current level. The inspection revealed a damaged area inside the gun cavity at the cathode wall in the vicinity of the rf contact spring. Further operation of this gun cavity for the FEL user facility was not possible and it was decided to exchange the gun. The gun which was under characterization at PITZ at that time (gun prototype 4.1) was dismounted and shipped to the FLASH injector. After installation and short commissioning it was successfully put into operation.

Long-Term Tests

A long-term test (LTT) implies continuous operation of the gun at ~700 μs rf pulse duration. A feedback has to be applied in order to provide rf field amplitude and phase flatness within the pulse train as well as the shot-to-shot stability [5]. Production of photo electron bunch trains of up to 650 pulses with 1 μs spacing at a train repetition rate of 10 Hz also has the goal to perform heavy load tests for the photo cathodes and the cathode laser system. A charge of ~1 nC for the individual electron bunches within the pulse train was considered as a goal during the LTT, the cathode laser pulse train intensity profile was tuned in order to flatten out the charge profile of the electron bunch trains as much as possible. But due to currently limiting factors of the overall setup there were some imperfections observed in the pulse train charge profile. Figure 1 illustrates an example of a long train of electron bunches. 630 pulses were accelerated, the mean charge of the train is 0.86 nC, the rms charge variation is ~3%. The output laser energy was not sufficient to produce 1 nC for the chosen laser spot size (~1.4 mm diameter).

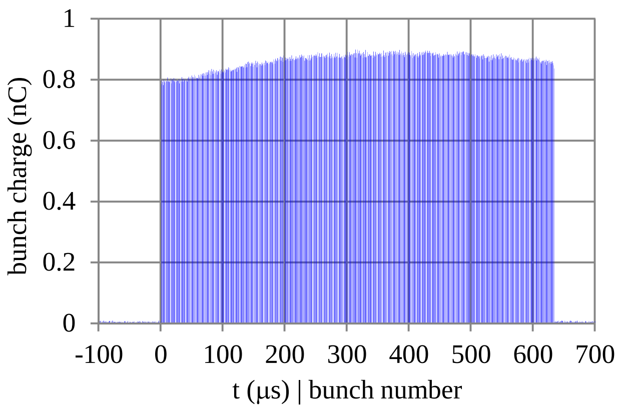

Figure 1: Long pulse train of electron bunches.

The peak power in the gun cavity was considered as variable machine parameter with the gun trip rate as observed value. The rf peak power in the gun P_{gun} was varied from 6 MW down to 3.5 MW in several steps during the LTTs performed at PITZ in 2012. Because of the strong electron beam energy dependence on the peak power in the gun several scaling rules were applied. In order to take into account the charge production enhancement due to the presence of a high electric field at the cathode the rms laser spot size was scaled according to the equation $\sigma^l_{xy}=0.3mm\cdot(6.5MW/P_{gun})^{1/2}$. The main solenoid current I_{main} was scaled, based on the measured maximum mean beam momentum $P_{z,max}$ obtained from the gun phase scan for a given rf peak power in the gun: $I_{main}=395A\cdot(P_{z,max}/6.477MeV/c)$. This provides similar focusing conditions which is important for the transport of electron bunch trains with rather high average power.

The gun interlock system includes two photodiodes (PDs) and two infrared detectors located at the rf windows from the SF_6 side, one photomultiplier (PMT) located at the vacuum waveguide after the T-combiner and orientated towards the T-combiner and an electron detector located near the PMT. The ultra-high vacuum is measured using two vacuum ion getter pumps (IGPs) near the gun coupler, one of which is integrated into the gun interlock system. The typical recovery time of ~40-50 min after an interlock includes rf ramping which should be synchronized with cavity resonance temperature tuning by intelligent combining of the rf heating and the water cooling of the gun body, rf feedback adjustment and establishing photo electron pulse train production. Such a long gun recovery time makes specifications for a gun trip rate rather stringent. One gun trip per day is considered currently as a goal to be demonstrated at PITZ. Such highly stable performance was not possible to be shown for the current hardware setup. While at highest rf peak power level (~6 MW) significant vacuum activity was observed, mainly light sensors (PDs and PMT) were limiting the operation at moderate and lower rf peak power levels. One of possible reasons could be imperfect TiN coating of rf ceramic windows. After replacing the T-combiner with two rf windows by a single rf window (which took place during installation of the gun at FLASH) a trip rate of less than 1 per week at 4 MW rf power in the gun was observed.

Monitoring photo cathode emission properties, e.g. charge production, is another substantial part of the LTTs. For example, the quantum efficiency (QE) and QE-maps of the Cs_2Te cathodes #613 and #13 [6] were measured in the beginning and at the end of one run week when LTTs were performed. The QE for the cathode #613 was measured for various laser spot diameters at the cathode (1.6, 1.2 and 0.8 mm) resulting in QE=(12.0±0.4)% before the tests (week 12/2012) and QE=(7.1±0.6)% after the week of run. Corresponding QE-maps are shown in the upper row of Fig. 2. The QE=9.7% for the cathode #13 was measured before week 15/2012 for 1.2 mm laser spot diameter, the same measurement repeated after one week LTT yielded QE=8.9%. Corresponding QE-maps are shown in the lower row of Fig. 2.

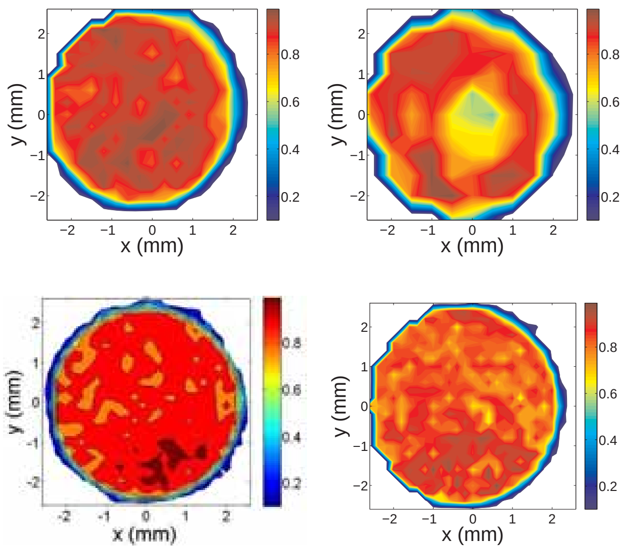

Figure 2: QE maps of the cathode #613 (upper row) and cathode #13 (bottom row) measured before a long-term test (left column) and after one week of run (right column of plots).

The detected QE degradation is mainly due to photo electron production and seems to be strongly cathode dependent. Despite the rf activity which is causing a general vacuum pressure increase (e.g. from $5{\cdot}10^{-11}$ mbar to $1.5{\cdot}10^{-10}$ mbar at 6 MW peak rf power and 700-750 μs pulse duration), the QE of cathode areas which were not involved in the photo electron production remained about constant.

Dark Current

The dark current from the rf gun is a key issue for the successful operation of a superconducting linac. The dark current was measured at PITZ for gun 4.1 right before the gun dismounting and shipment to FLASH. The dark current signal was measured using a Faraday Cup inserted at the first diagnostic cross (~0.8 m from the cathode). Results are shown in Fig. 3 as a function of the main solenoid current for different values of the peak power in the gun.

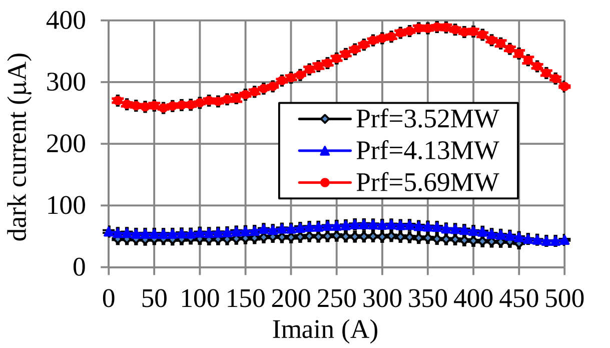

Figure 3: Dark current from the gun as a function of the main solenoid current, measured for different levels of rf peak power in the gun.

A maximum peak power of ~4 MW is currently the nominal value for the FLASH rf gun and the dark current level under 70 μA fits the requirements of the FLASH user facility.

RECENT DIAGNOSTICS UPGARDES

Two major components were installed in 2012 in the PITZ beam line – a transverse deflecting cavity and the second high energy dispersive arm. One important application of these diagnostic devices is the measurement of electron bunch slice parameters.

TDS

The transverse deflecting system (TDS) is an S-band traveling wave disc-loaded structure operated at 2.997 GHz in 2π/3 mode [7]. It should allow to streak vertically short electron bunches with energies up to ~30 MeV in order to measure their temporal profile with sub-picosecond resolution. Horizontal slice emittance measurements are enabled by using the tomography module downstream of the TDS [8].

The cavity is installed in the PITZ linac at a z-location of ~11 m from the photo cathode plane. The rf power supply system including a 3 MW CPI klystron is installed as well. A 40 m waveguide line is under completion. Commissioning of the TDS is expected in autumn 2012.

HEDA2

The second high energy dispersive arm (HEDA2) is a multipurpose diagnostic device [9]. It consists of three dipole magnets which allow utilizing a beam dump common with the straight electron beam line. Extensive diagnostics components are designed to monitor long pulse train operation needed for further LTTs.

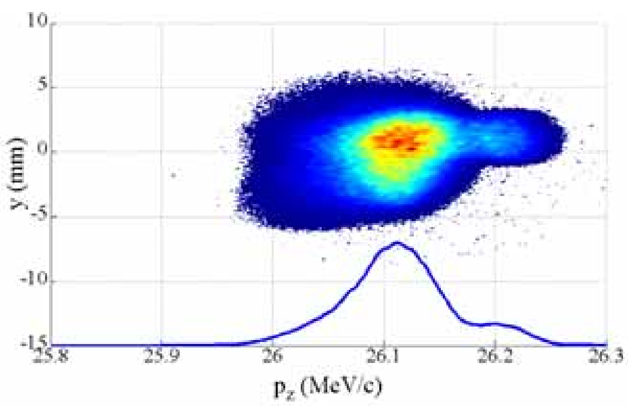

Figure 4: Electron beam image measured at the first screen of the second dispersive arm. Horizontal axis corresponds to the longitudinal momentum distribution.

Combined with the TDS it can be used for single shot measurements of the longitudinal phase space. By introducing a linear energy chirp in the electron bunch with off-crest CDS booster operation it is possible to measure the vertical slice emittance. First beam measurements at HEDA2 have been performed in spring 2012. An example of electron beam image measured at the first HEDA2 screen is shown in Fig. 4 together with the longitudinal momentum distribution. Further commissioning of the second dispersive arm is ongoing.

CONCLUSIONS

Long term tests for full average power of the rf gun were performed at PITZ in 2012. The trip-rate dependence on the peak power was estimated and is still not satisfactory. Improvement was observed using a different rf window with a better TiN coating. A photo cathode QE degradation due to photo electron production was observed, its dependence on the operation mode and particular cathode pieces was established. Further tests are planned.

Diagnostics upgrade is ongoing at PITZ and, in particular, systems for time-resolved electron bunch measurements are under commissioning.

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