GENERATING LOW TRANSVERSE EMITTANCE BEAMS FOR LINAC BASED LIGHT SOURCES AT PITZ*

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Abstract

At the Photo Injector Test facility at DESY, Zeuthen site (PITZ), high brightness electron sources for linac based Free Electron Lasers (FELs), like FLASH and the European XFEL are developed and characterized. The electrons are generated via the photo effect using a cesium telluride (Cs_2Te) cathode and are accelerated by an 1.6-cell L-band RF-gun cavity with a maximum accelerating gradient at the cathode of about 60 MV/m. The characteristics of the photocathode laser pulses have been optimized using a laser pulse shaping method yielding small emittances. The transverse projected emittance is measured by a single slit scan technique. The measurement program in the last run period at PITZ concentrated on emittance measurements for the nominal 1 nC beam and emittance optimization for lower bunch charges. The recent results show that normalized projected emittances of below 1 mm-mrad for 1 nC charge can be realized at PITZ. The facility set-up and measurement results including their uncertainties will be reported and discussed in this contribution.

INTRODUCTION

Linac based FEL light sources require electron beams of high quality, e.g. short electron bunches with small energy spread and small transverse emittance. Research activities at PITZ combine development and optimization of electron sources to produce electron beams yielding the requirements for FLASH and the European XFEL. The required transverse emittance for the European XFEL is 1.4 mm-mrad at the undulator entrance corresponding to 0.9 mm-mrad at the injector for 1 nC bunch charge.

The PITZ set-up in the 2009 run period is shown in Fig.1. The laser driven electron source is based on an L-band RF cavity and a Cs_2Te photocathode. It is powered by a 10 MW klystron via an RF coaxial coupler. The gun is surrounded by main and bucking solenoid magnets for beam focusing to counteract the space charge effect. The dry-ice sublimation-impulse cleaning technique using a special rotatable nozzle has been applied to the gun cavity [1]. This leads to a significant dark current reduction by a factor of 10 compared to the previous guns [2]. The European XFEL RF parameters for the injector have been demonstrated for 50 kW average power with 7 MW peak power, 700 μs flat-top RF pulse length and 10 Hz repetition rate.

A diode pumped Yb:KGW/Yb:YAG laser system has been developed by the Max-Born Institute (MBI) and installed at PITZ in 2008. It can produce up to 800 micro pulses per train at currently 1 MHz repetition rate. The UV output pulses have a wavelength of 257 nm and the maximum energy of $\sim$10 μJ per micro pulse. Since the temporal laser profile is one of the main keys for the photo injector, the laser system has been designed to be able to generate a flat-top temporal pulse shape [3]. Laser temporal profiles used in the measurements mentioned in this paper are flat-top pulses with 23-25 ps FWHM and 2-4 ps rise and fall time. The laser spot size at the cathode has been varied to achieve the minimum emittance value. Details of other components in the PITZ beamline can be found in [4].

EMITTANCE MEASUREMENTS

A single slit scan technique is used to measure the transverse emittance and the phase space. The Emittance Measurement SYstem (EMSY) consists of horizontal and vertical actuators with 10 and 50 μm slit masks and YAG/OTR screens for the beam size measurement. The local divergence is estimated by transversely cutting the beam into thin slices and measuring the size of the beamlets created by the slit at a screen downstream of the slit location. In standard measurements for 1 nC bunch charge, the 10 μm slit and a drift length of 2.64 m are used. Emittance optimizations in the run periods prior 2009 were described in [5, 6].

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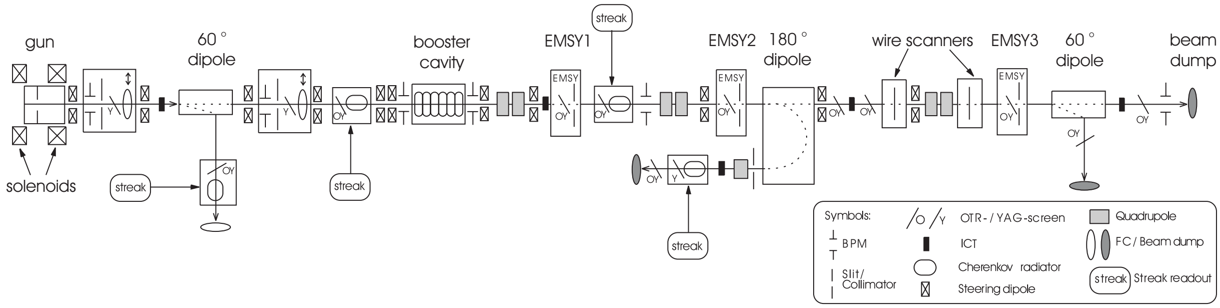

Figure 1: Layout of the Photo Injector Test facility at DESY, Zeuthen site, (PITZ) in the 2009 run period.

Improvements in Measurement Procedure

Since the single slit scan technique is not a single shot measurement, uncertainties from the machine instability and the measurement procedure are included in the slit scan data. In the 2009 run period, the emittance measurement procedure has been improved to accelerate the slit scan and the data taking by continuously moving the slit through the beam with constant speed. At the same time, the images at the beamlet observation screen are recorded by a CCD camera with fixed rate. The scan and data taking time for one measurement is about 20 second, compared to 30 minutes for the old procedure in 2007. Since the measurement time is greatly improved, several slit scans per one solenoid setting are possible for a given time. This allows us to distinguish between uncertainties of measurement procedure and effects of jitter and drifts in the machine parameters.

In addition, more accurate criteria for the beamlet image quality by using the full dynamics range of the CCD camera with 12 effective bits have been defined. This procedure includes checking on pixel saturation after the scan and taking the statistics over all pixel in all beamlets. The cut in charge and phase space distribution has been minimized to achieve the so called 100% RMS emittance [5, 6].

Improvement in Emittance Analysis

The so called "2D scaled normalized projected emittance" formula was used to obtain the emittance value.

$$\varepsilon_n = \beta\gamma \frac{\sigma_x}{\sqrt{\langle x^2 \rangle}} \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle - \langle xx' \rangle^2}, \qquad (1)$$

where $\langle x^2 \rangle$ and $\langle x'^2 \rangle$ are the second central moments of the electron beam distribution in the phase space obtained from the slit scan, $x' = p_x/p_z$ is the angle of the single electron trajectory with respect to the whole beam trajectory, σ_x is the RMS beam size measured at the slit location and the factor $\beta\gamma$ corresponds to the electron beam energy. The difference from the usual normalized emittance formula is the scaling factor of the RMS beam size measured on a screen at the slit position (σ_x) and the beam size estimated from the slit position and the beamlet intensity on the observation screen ($\sqrt{\langle x^2 \rangle}$). The factor ($\sigma_x/\sqrt{\langle x^2 \rangle}$) is introduced to correct for low intensity losses from the beamlet measurements. This results in a conservative emittance estimation because the scaling factor is practically always larger than 1.

MEASUREMENT RESULTS

For the measurements of the nominal 1 nC bunch charge, the minimum emittance value has been measured for a laser temporal profile of 23 ps FWHM and 2 ps rise and fall time. The laser spot size at the cathode was 0.36 mm RMS. The beam momenta have been measured after the gun and the booster cavity using spectrometers with corresponding screens in the dispersive sections. For an accelerating gradient of 60 MV/m at the cathode a maximum momentum of 6.7 MeV/c with a momentum spread around 10-20 keV/c has been measured after the gun. The phase of this measurement is referenced at phase of maximum mean momentum gain (MMMG). With these settings of the gun, after the acceleration by the booster cavity, a momentum of 14.8 MeV/c with a spread of 150 keV/c has been achieved. The phase of the booster has been set to the phase of MMMG.

An exemplary result of the 1 nC emittance measurements in Fig.2 and 3 shows that a geometric average emittance (ε_{xy}) of 0.98 mm-mrad has been measured at a gun phase of +6 degree from MMMG phase. By removing 10% from the total bunch charge from the low intensity regions of the measured transverse phase space, i.e. removing electrons probably not contributing to the lasing process, a normalized transverse emittance as low as 0.76 mm-mrad can be achieved.

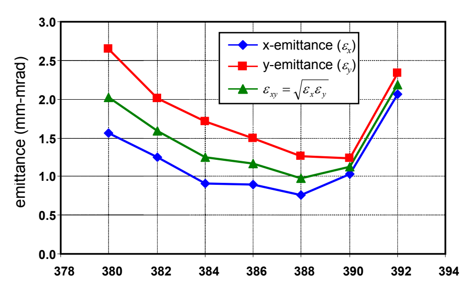

Figure 2: An example of a measurement of the transverse normalized projected emittance for different main solenoid currents at a bunch charge of 1 nC.

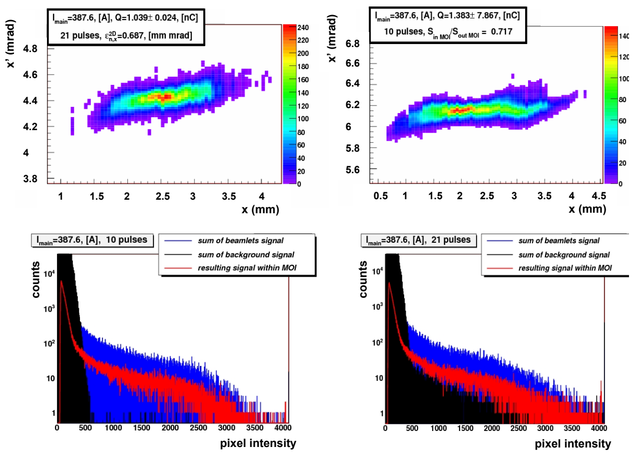

Figure 3: Transverse phase space distributions and the corresponding beamlet intensity spectrum during the measurement for the horizontal (left) and the vertical (right) plane of the best point obtained from the solenoid scan measurements in Fig.2.

Statistic measurements for the same machine setting have been performed. The best results with 4 subsequent measurements for the horizontal and the vertical plane within a total time peroid of 30 minutes results in a geometrical average of 0.89±0.01 mm-mrad for 100% RMS value. Later short term measurements for 3-4 hours showed an RMS uncertainty of the emittance values of about 4-7%, while the long term measurements over four days showed emittance fluctuations of 6-8.5% RMS. From the run experience, we observed RF gun phase jittering of about 10-15 degree peak-to-peak that are considered to be the main reason of the emittance fluctuations. The gun phase jitter causes jitter of the beam momentum and thus different focusing condition yielding to beam size fluctuation. This effect occurs during the single slit scan procedure and results in smearing of the phase space and therefore an increase of the measured emittance. Moreover, the phase slope within the pulse train adds additional source of jitter to the measured emittance values.

Simulations using the computer code ASTRA [7] have been performed and the results suggested that a smallest emittance of about 0.6 mm-mrad is obtainable with a gun phase of -0.5 degree from the MMMG phase for a flat-top laser pulses of 23 ps FWHM, 2 ps rise/fall time and 0.40 mm RMS laser spot size [6]. Simulations of the influence of the gun phase jittering to the beam size and emittance have been performed by overlapping the phase space distributions for the gun phases around the minimum emittance phase. Then, the RMS beam size and the emittance have been calculated from the overlapping distributions. The simulation results in Fig.4 show that the emittance and beam size increase significantly for larger gun phase jittering. For a phase jittering of ±5 degree peak-to-peak, the emittance increases by 26% corresponding to an increased emittance value of 0.77 mm-mrad, which is closer to the value obtained from the measurement. However, discrepancies between the simulations and the measurements for the gun launch phase, the laser spot size and the absolute emittance value still remain and will be studied further.

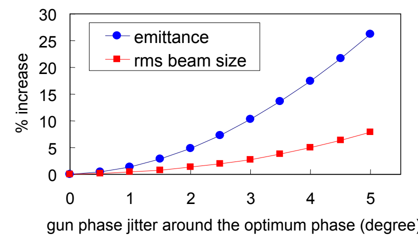

Figure 4: Simulated emittance and beam size increasing due to the gun phase jittering (peak-to-peak).

CONCLUSION AND OUTLOOK

Major electron beam parameters for FLASH and the European XFEL were demonstrated at PITZ in the 2009 run period. Long pulse trains of 700 pulses at 1 nC have been produced for the accelerating gradient of about 60 MV/m at the cathode. Small transverse projected emittances below 1 mm-mrad for 1 nC bunch charge have been measured. Currently, the RF gun described in this paper has been installed and is under commissioning at FLASH.

A new RF gun cavity of the same design and production as the previous one is now installed at PITZ. Presently, it is in the conditioning process. To improve the gun phase stability, a 10 MW in-vacuum directional coupler has been installed after the T-combiner. This should allow a direct monitoring and control of the combined forward and reflected RF waves. The feedback control for the RF will be simpler and more straightforward than for the previous setup. Low power tests showed that the principle works. The experimental program with the new gun cavity to optimize and characterize the beam properties will be continued with the ongoing upgraded facility.

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