RECENT ELECTRON BEAM MEASUREMENTS AT PITZ WITH A NEW PHOTOCATHODE LASER SYSTEM*

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Abstract

The Photo Injector Test facility at DESY, Zeuthen site, (PITZ) aims to develop and optimize electron sources for frontiers linac based FELs such as FLASH and the European XFEL. A new laser system has been commissioned at PITZ in late autumn 2008. It is capable to deliver trains of laser pulses with challenging temporal shape: flat-top profile with ~20 ps FWHM and rise and fall times of ≤2 ps. This laser system, being a significant step towards the European XFEL photo injector specifications, has been used in a 1.6-cell L-band rf gun with up to ~60MV/m electric field at the cathode to produce high brightness electron beams. A major part of the PITZ measurement program is the optimizing of the transverse phase space. Recent electron beam measurements at PITZ will be presented.

INTRODUCTION

The PITZ facility develops and optimizes high brightness electron sources for linac driven Free Electron Lasers (FELs), such as FLASH [1] and the European XFEL [2]. The main challenge for PITZ is a production of electron beams with extremely low transverse emittance at the nominal bunch charge of 1 nC. In August 2007, an extensive machine optimization resulted in the minimum rms transverse projected emittance of 1.26 mm mrad [3]. The cathode laser used for these results had a flat-top temporal profile with ~24 ps FWHM and 6-8 ps rise and fall time. ASTRA simulations demonstrated [4], that a decrease of the rise and fall time from 6 ps to 2 ps should result in a ~30% reduction of the transverse projected emittance. The correspondent cathode laser system upgrade has been made in 2008. This system is capable of producing laser UV pulses with rise and fall time of ~2 ps. Since the PITZ linac has also been significantly upgraded, a new machine optimization is necessary. The paper presents recent results of the emittance optimization at PITZ.

THE UPGRADED PHOTOCATHODE LASER SYSTEM

One of the major changes at PITZ since 2007 is the photocathode laser system upgrade. An entirely new photocathode drive laser has been developed at Max-Born-Institute in Berlin and installed at PITZ in September 2008. Figure 1 shows an overview of the new laser system. It is a single channel, high bandwidth system with a pulse shaper based on a multicrystal birefringent filter [5]. A diode pumped Yb:KGW laser oscillator generates short Gaussian pulses with 1029 nm wavelength, which after the pulse selector form a pulse train with 1 MHz repetition rate within. The pulse shaper allows to transform the initial Gaussian pulse shape into a flat-top profile. Initially the pulse shaper at PITZ contained 10 birefringent crystals yielding ~20 ps maximum pulse length (FWHM). Later the shaper was extended by adding 3 crystals, allowing a maximum pulse length of ~24 ps in order to study the dependence of electron beam performance on the pulse length. The shaped pulses are passing through regenerative and two-stage Yb:YAG amplifiers. Two SHG crystals are used to convert the IR laser pulse into UV (wavelength 257 nm).

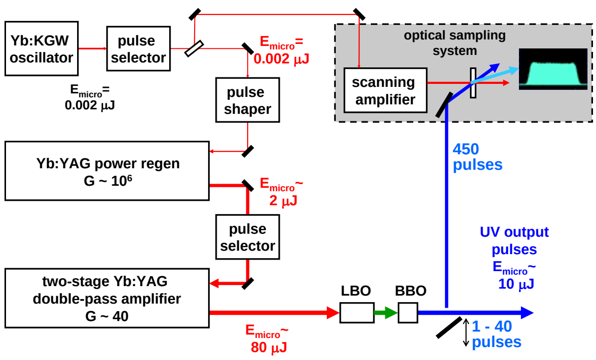

Figure 1: Scheme of the upgraded cathode laser system, including an optical sampling system (OSS).

To measure the temporal pulse shape an Optical Sampling System (OSS) is applied. The temporal profile of the output UV pulses is measured by cross-correlating

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them in BBO crystals with subpicosecond pulses that are generated by the oscillator. Typical temporal profiles measured with the OSS are shown in Figure 2 together with flat-top fits.

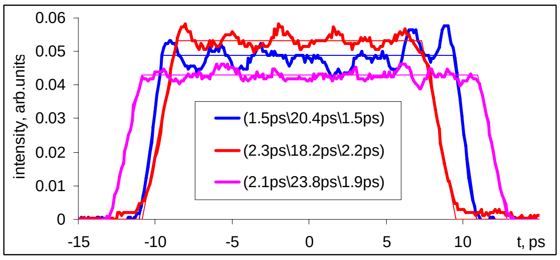

Figure 2: Typical temporal profiles of a UV pulse with the new cathode laser system. The legend contains results of the corresponding flat-top fits (rise time \ FWHM \ fall time).

EMITTANCE OPTIMIZATION

The projected beam emittance is measured at PITZ by the slit method [3], using a single slit scan technique. The Emittance Measurement SYstem (EMSY) besides a YAG screen, used for measurement of the whole beam size, also contains horizontal and vertical actuators with 10 and 50 μm slit masks. Beamlets created by the slits are measured at YAG screens at some distance downstream of EMSY. The slit opening (10 μm) and the distance between slit mask and the beamlet screen (2.64 m) have been adjusted according to the increased beam energy and phase space expected to be measured.

The basic measurement during emittance optimization studies is the so called solenoid scan, i.e. an emittance measurement as a function of the main solenoid current. The solenoid current is varied within ~10-15 A around the beam focus at the EMSY screen. Typically the optimum solenoid current (delivering minimum measured emittance) can be found in 2-5 A above the focussing value. The bucking solenoid is always set to compensate the longitudinal magnetic field at the photo cathode. A fast slit scan with 200 μm steps (i.e. typically 20-30 beamlets taken for each plane) is used during a solenoid scan. The best point obtained is to be repeated with a fine slit scan with 50 μm steps, resulting in ~100 X- and Y-beamlets, which are also taken with better shot-to-shot statistics.

An important parameter for the electron beam phase space optimization in photo injectors is a transverse laser distribution at the cathode. The transverse laser spot size at the cathode is controlled at PITZ by imaging a definite diaphragm – the Beam Shaping Aperture (BSA). A plate with a set of BSAs determines the steps in the laser spot size variation.

Changes in the PITZ beamline

The booster (normal conducting copper TESLA cavity) has been shifted by ~0.6 m downstream. The new booster position corresponds to the gun gradient of ~60MV/m and has been obtained from beam dynamics simulations. The position of the first EMSY has also been shifted to z=5.74 m, what corresponds to the location of the expected emittance minimum.

Emittance measurement for the "2007"-laser temporal profile

The new photo cathode laser is capable to produce a wide variety of temporal profiles [5]. After corresponding pulse shaper tuning the profile measured in 2007 using a streak camera [3] has been reproduced. Figure 3 shows profiles obtained from the streak camera (Hamamatsu C5680) and OSS measurements. Due to the restricted resolution the streak camera measurement shows longer overall length, bigger rise and fall time, as well as lower dip in the middle of the pulse.

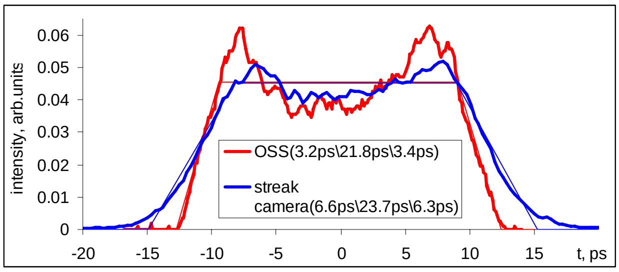

Figure 3: Laser temporal profile close to those obtained in 2007, reproduced with the new cathode laser system. Two curves obtained from OSS and streak camera measurements are shown with flat-top fits.

The standard optimization procedure (both the gun and the booster on-crest) resulted in ε_{xy} =1.58 mm mrad. For further improvement the gun launch phase has been chosen as an optimization parameter. The results of the optimization are shown in Figure 4, where minimum values of $\varepsilon_{xy} = \sqrt{\varepsilon_x \varepsilon_y}$ are summarized for BSA=1.5 mm (corresponding laser rms spot sizes σ_x=0.34 mm and σ_y=0.36 mm). The maximum longitudinal momentum of the beam for these studies was measured to be 14.5 MeV/c (the booster was always kept on-crest).

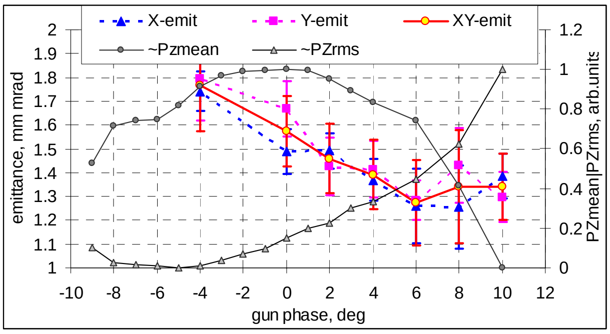

Figure 4: Measured emittance vs. gun launch phase. Normalized mean momentum and rms momentum spread of the electron beam after the gun are plotted at the right axis. The zero phase is referred to as the phase of the maximum momentum gain from the gun.

The solenoid scan for the best gun phase (+6 deg off-crest) is shown in Figure 5. Gun phase variation and solenoid optimization resulted in ε_x=1.28±0.20 mm mrad and ε_y=1.29±0.15 mm mrad, what is in a very good agreement with results obtained in 2007 [3]. The electron beam transverse phase space measured for this point is illustrated in Figure 6. One can see that the electron beam at EMSY has a significant tilt. The origin of this tilt is not yet clear, investigations are ongoing. Another feature of the electron beam transverse distribution is a hollow structure which is a sign of the space charge effect (charge lowering results in a disappearing of the hollow structure, but not the tilt).

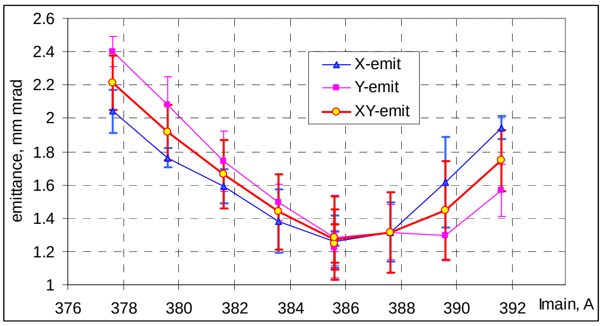

Figure 5: Measured emittance vs. main solenoid current for the gun phase 6 deg off-crest. BSA=1.5 mm.

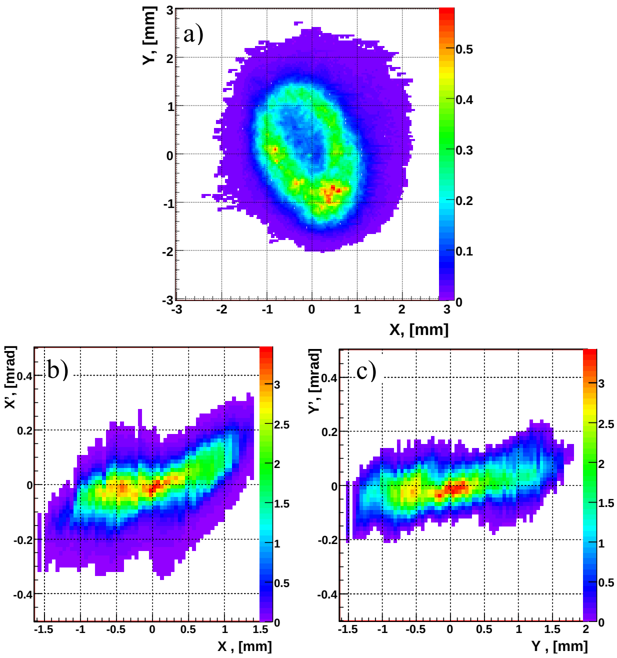

Figure 6: Transverse phase space of the optimized electron beam: a) x-y beam distribution at EMSY; b) horizontal phase space; c) vertical phase space.

One major difference between the obtained optimum machine setup and the machine settings in 2007 is the gun launch phase. Whereas the rf gun at that time was operated at the phase of the maximum momentum gain (on-crest), the recent optimum phase is +6 deg off-crest. This difference still has to be understood in detail and might be related to the exchange of the gun cavity and to the shift of the booster and EMSY positions. Even though both cavities (the old and the new one) have the identical electromagnetic design, small deviations in fabrication and treatment could result in some difference of the rf fields and, therefore, in the dynamics of the electron beam. Also longer propagation of the space charge dominated beam to the booster could require different phase correlations within the beam. These questions are now under detailed investigations.

The experimental program will also be continued with the longitudinal laser pulse shapes modified towards shorter rise and fall times which are accessible now.

CONCLUSIONS AND OUTLOOK

A new photo cathode laser system has been commissioned at PITZ and is capable to produce trains of flat-top UV pulses with rise and fall time shorter than 2 ps. The smallest emittance measured in 2007 has been reproduced by application of the similar laser temporal profile (6-7 ps rise and fall time), but the gun has to be run +6 deg off-crest, whereas the operation in 2007 was on-crest. Further emittance optimization studies, including temporal profile and launch phase variations are ongoing at PITZ.

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