FIRST RESULTS OF SLICE EMITTANCE DIAGNOSTICS WITH AN ENERGY CHIRPED BEAM AT PITZ

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Abstract

Recent successes in existing linac based FEL facilities operation and improvements in future FEL designs became possible due to detailed research in high-brightness electron beam production. The Photo Injector Test facility in Zeuthen (PITZ) is the DESY center for electron source characterization and optimization. New slice emittance diagnostics was recently commissioned at PITZ. In the measurement approach a bunch is accelerated off-crest in the accelerating cavity downstream the gun, a part of the bunch is selected after a dipole with a slit perpendicular to the dispersive direction, and the transverse emittance of the bunch part is measured using a quadrupole or a slit scan. Test measurement results are presented for 1 nC charge, flat-top and Gaussian longitudinal laser shapes.

INTRODUCTION

Photo Injector Test facility in Zeuthen [1] specializes at characterizing the RF photo cathode electron sources for the Free electron LASer in Hamburg (FLASH) . Recently transverse emittance results that even surpass the European X-ray free electron laser source requirements were demonstrated at PITZ [2].

The facility contains the RF gun, an additional accelerating (booster) cavity and diverse electron beam diagnostics. The nominal operation mode is 1 nC bunch charge, 20 ps FWHM flat-top laser profile, pulse repetition rate 1 MHz, up to 800 laser pulses within the RF pulse, and RF pulse repetition rate of 10 Hz. The main purpose of PITZ is to optimize the injector setup to produce the smallest achievable transverse emittance.

The projected emittance looses the details of the transverse dynamics within the bunch. Additional information can be obtained with a transverse phase space diagnostics that has a temporal resolution shorter than the bunch. The sub-bunch time resolved transverse emittance measurement is referred to as slice emittance diagnostics. The same projected emittance can be built up by constant σ_{x,p_x} covariance along the bunch and larger slice emittance or can be built up by varying covariance and smaller slice emittance.

In this paper the first results of the slice emittance measurements at PITZ are presented. An energy chirped beam is used for the measurements. It is a similar approach to the one used in reference [3]. The realization details are discussed below.

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In Fig.1 one can see the setup up to the dispersive section after the energy boosting cavity. The simplified scheme includes the elements used for the slice emittance measurements.

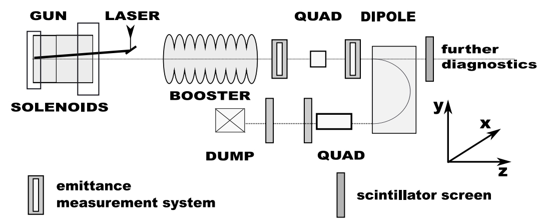

Figure 1: A scheme representing the PITZ components involved in the slice emittance measurement

SLICE EMITTANCE SETUP AND THE MEASUREMENT METHOD

The first step in a slice emittance measurement is to separate the longitudinal bunch slices for the emittance analysis. In practice one needs to convert the bunch longitudinal distribution in one plane into a transverse distribution and analyze the beam size in the orthogonal transverse plane.

In the energy chirped beam approach the bunch particle gets an energy gain dependent on its longitudinal position within the bunch. This can be achieved by off-crest phase acceleration The on-crest phase refers to the phase of maximum mean energy gain. Off-crest phase in this sense corresponds to any phase shift from the on-crest case. The positive shift is defined towards the minimum energy spread phase. The positive shift leads to bunch compression. Hence the negative phase shift is chosen for the slice emittance measurements. The position-energy correlation is used to map the longitudinal distribution onto transverse distribution in the dipole.

At PITZ the booster cavity is used to accelerate the beam off-crest. The 180 deg dipole maps the momentum distribution onto the Y transverse plane. Changing the dipole current shifts the bunch across the analysis region. In this way one chooses the temporal slice.

The PITZ setup allows to measure only horizontal (X) transverse emittance. The emittance measurements can be done using the quadrupole magnets before or after the dipole or using the slit mask before the dipole. This paper covers the quadrupole scan results only. More about the design details can be found in [4].

The quadrupole magnet in front of the dipole has a field length of only 4 cm and the drift to the measurement screen (the second screen in the dispersive section) is 3.8 m long.

It is situated at 7 m downstream from the cathode. The dispersive section quadrupole magnet field has an effective length of 22 cm and is positioned at 9 m downstream from the cathode. The drift space between the quad and the second screen downstream is 1.25 m.

The quadrupole magnet current is scanned in the vicinity of the value corresponding to the smallest beam size at the screen. A linear transfer matrix model is used to fit the beam X size scan versus the quadrupole strength. The central 5 mm (along momentum direction) wide region at the screen is used for the emittance analysis. It causes that the raising vertical defocusing makes the slice particle content smaller. The procedure still guarantees that the remaining particles form a subslice of the initial charge fraction. In the next run period a 5 mm slit on the dipole exit will be install to cut the slices out right after the dipole in the dispersive section.

For the data consistency the projected emittance is measured 5.7 m downstream from the cathode. The measurement is done using the first slit mask after the booster cavity. The booster phase is chosen to gain maximum mean energy. The 10 μm slit is used. The divergence profiles are taken on the screen placed 2.6 m downstream. The smallest value of the solenoid scan is given in the results section.

RESULTS

Flat-top Laser Temporal Profile

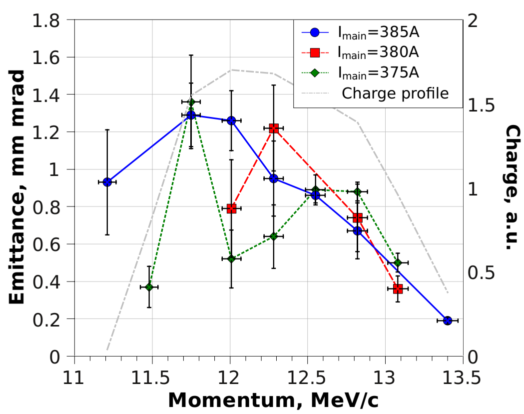

Figure 2: Slice emittance of the charge within the momentum range indicated by the horizontal error bars for the case of the flat-top laser shape at the cathode.

The measurement with a flat-top temporal laser profile was done using the quad in front of the dipole. The measured laser pulse FWHM duration is 23 ps with rise and fall time of 2 and 3.5 ps correspondingly. The measurement is done with -50 deg off-crest phase shift. The laser spot on the cathode is 1.2 mm in diameter. The laser intensity is adjusted to have total bunch charge of 1 nC at the gun. The slice emittance was measured for three solenoid current values of 375 A, 380 A and 385 A. On Fig.2 the results of the measurement for three different solenoid currents are

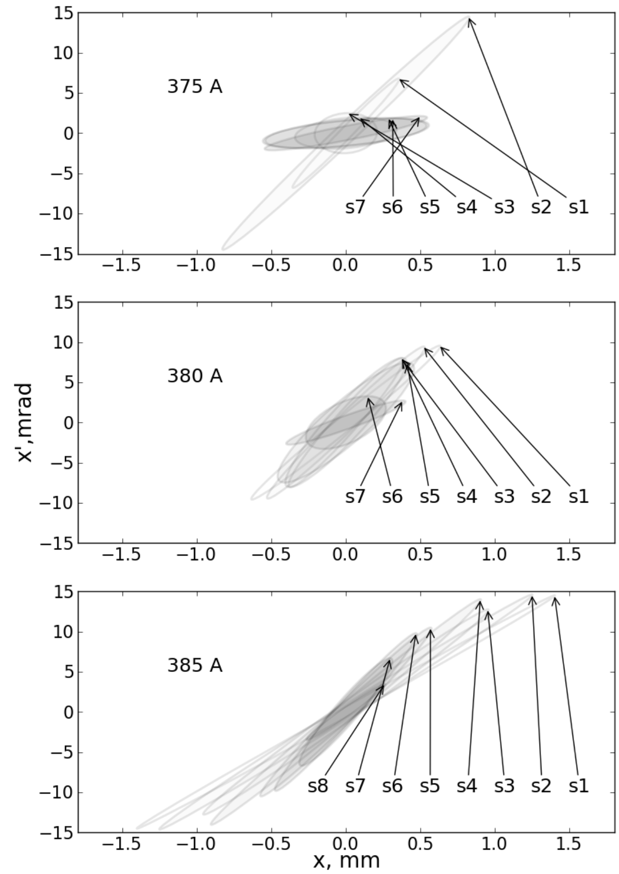

Figure 3: RMS equivalent slice ellipses in the trace space for the case of the flat-top laser shape at the cathode. The slice numbering starts from the bunch tail.

presented. Comparison of the steady trace space distributions reconstructs the trace space dynamics (Fig.3). The lowest beam projected emittance of the beam in X plane is 1 mm mrad and in Y plane is 1.16 mm mrad.

Gaussian Laser Temporal Profile

This set of measurements is presented for a temporal Gaussian laser pulse (RMS duration $\sigma_\tau = 5$ ps). The bunch charge at the gun at the maximum mean momentum phase is 1 nC. The beam projected x and y emittance correspondingly equal to 1.27 and 1.40 mm mrad. Negative 50 deg off-crest phase shift is chosen for the booster. The quad scan is done for three different main solenoid currents 368 A, 371 A, 375 A. The solenoid current 371 A corresponds to the minimum size at the second slit mask after the booster which is close to the dipole entrance.

The vertical error bars contain the statistical error and the error of the transfer model fit. The vertical beam size at the dipole entrance has the largest contribution to the limited temporal resolution that is estimated to be about 2.5 ps. For the momentum-to-time calibration a streak camera will be applied next run period.

Similar to the flat-top case the steady trace space dis-

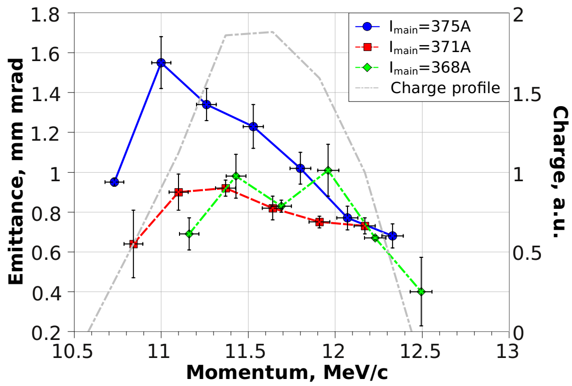

Figure 4: Slice emittance of the charge within the momentum range indicated by the horizontal error bars for the case of the Gaussian laser shape at the cathode.

tributions are presented for the set of solenoid currents (Fig.5).

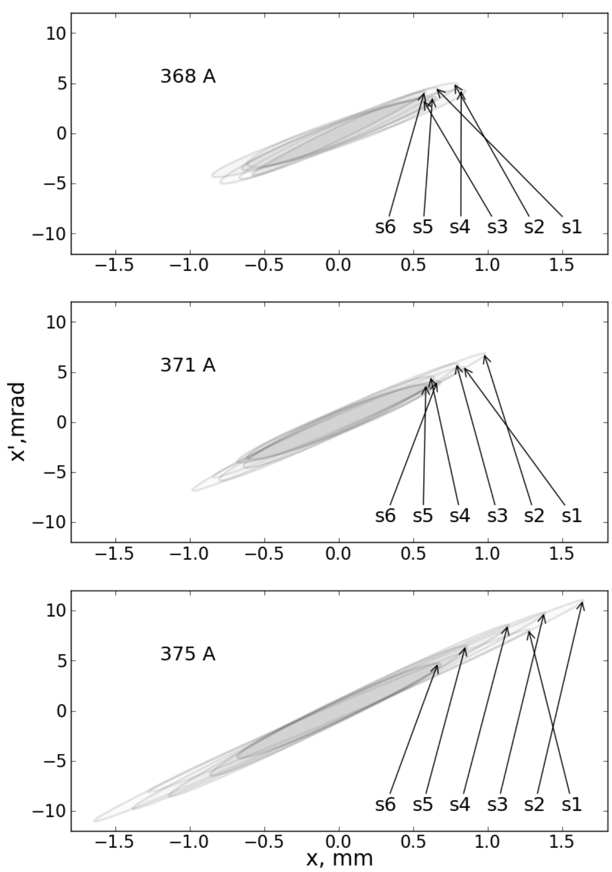

Figure 5: RMS equivalent slice ellipses in the trace space for the case of the gaussian laser shape at the cathode. The slice numbering starts from the bunch tail.

CONCLUSIONS

PITZ beam diagnostics includes now the slice emittance measurement setup using an energy chirped beam. Commissioning of the setup is finished and several technical upgrades are on the way of realization (the new booster cavity, a vertical slit, a new read-out optics for the beam size measurement screen).

Slice emittance was measured for the flat-top and the Gaussian laser pulse temporal shapes. The measurement results are summarized in Table 1. All the emittance values are normalized.

One has to underline that the results were obtained during test measurements and the reproducibility was not studied. An important issue of the run conditions was severe fluctuations of the gun phase [5]. This will be solved with the installation of an in-vacuum directional coupler to realize the feedback RF stability regulation.

Table 1: Slice Emittance Measurement Results Summary

Beam property	Flat-top	Gaussian
Charge, nC	1	1
Laser spot size, mm	1.2	1.5
Projected X emittance, mm mrad	1.00	1.27
Minimal of average slice emittance, mm mrad	0.77 ± 0.11	0.82 ± 0.04
Emittance for the peak current slice, mm mrad	0.58 ± 0.16	0.83 ± 0.06

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