SLICE EMITTANCE MEASUREMENTS FOR DIFFERENT BUNCH CHARGES AT PITZ

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Abstract

The successful operation of the free-electron laser FLASH at DESY brings up the interest in further broadening the spectrum of possible applications also for the upcoming European XFEL. Hence the electron beam properties required for lasing should be tested and optimized for a broad range of values already on the level of the injector.

The Photo Injector Test facility in Zeuthen (PITZ) at DESY characterizes the photo injectors for FLASH and the European XFEL. The main study involves the transverse projected emittance optimization for different beam conditions. Beside the projected emittance, the PITZ setup allows to measure the transverse emittance with a sub-bunch longitudinal resolution. This slice emittance diagnostics is based on the usage of bunches with an energy correlation of the longitudinal phase space components induced by the booster. Then the bunch is swept vertically with a dipole magnet. Part of the bunch that corresponds to a longitudinal slice is cut out by means of a vertical slit and the horizontal emittance is measured. This report presents the results of recent slice emittance measurements for different bunch charges.

INTRODUCTION

The Photo Injector Test facility in Zeuthen [1] characterizes the RF photo cathode electron sources for FLASH. A beam with transverse emittance fulfilling the European XFEL source requirements was demonstrated at PITZ [2].

Although projected emittance is a merit of the beam quality of the injector, FEL radiation is generated along the the whole compressed bunch, but there are several coherence spikes longitudinally [3], and the amplification of each of them depends only on the local electron bunch parameters. It is not possible to trace this charge portion back to the injector to study and optimize its transverse emittance, partially due to a non-linear compression process that is used to boost up the peak current. Still it is possible to correlate the FEL radiation output with transverse emittance of a certain longitudinal part of the bunch that contributes mostly to the radiating fraction. Following this way requires a transverse emittance diagnostics with a sub-bunch longitudinal resolution that is referred to as slice emittance diagnostics. This paper presents slice emittance measurement results for different bunch charges at PITZ.

MEASUREMENT SETUP

An energy chirped beam is used for slice emittance measurements at PITZ. The measurement setup is shown in Fig. 1 and is described in [4]. An electron bunch is generated and accelerated in the RF gun. The bunch is further accelerated in the second accelerating (booster) cavity. The acceleration is performed at phases that introduce a positive correlation to the longitudinal phase space distribution of the bunch (energy chirp). A 180 degree spectrometer magnet transforms the longitudinal distribution into a transverse one and the slit at the exit cuts a fraction of the bunch which is analyzed on the last screen in this dispersive section. The dipole current to momentum calibration is known from the setup geometry. Momentum to time calibration is done using a simulated momentum phase scan of a single particle in the booster cavity.

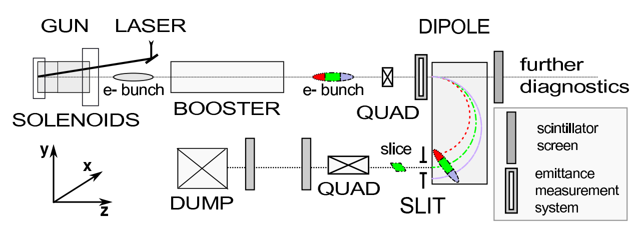

Figure 1: Setup for slice emittance measurements at PITZ.

SLICE EMITTANCE MEASUREMENTS WITH DIFFERENT BUNCH CHARGE

A set of slice emittance measurements using a quadrupole scan was performed for different bunch charges generated at the cathode: 100 pC, 230 pC, 500 pC, 1000 pC. A laser beam shaping aperture (BSA) is used to vary the laser spot diameter at the cathode. For the measurement with a bunch charge of 100 pC we use a laser spot size of 0.18 mm rms on the cathode. For all other measurements we use a laser spot size of 0.3 mm. The temporal laser shape is a flat-top pulse with FWHM of 21.1-21.4 ps.

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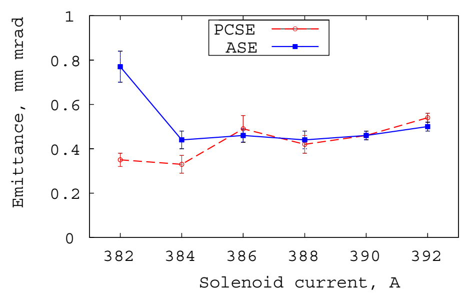

Figure 2: Slice emittance solenoid scan with 100 pC bunch charge. For ASE and PCSE see the text.

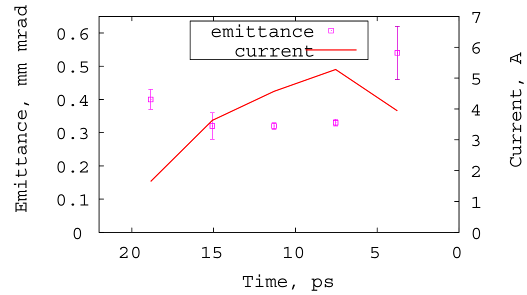

Figure 3: 100 pC slice emittance detailed measurement for solenoid current 384A.

The booster off-crest phase was chosen -20 degree (slice width of 5.8 ps) for 100 pC and -30 degree (slice width of 3.8 ps) for the other measurements.

Slice emittance is presented in the solenoid scan with the weighted Average Slice Emittance (ASE) and a Peak Current Slice Emittance (PCSE) - emittance of a slice with the maximum intensity. A detailed measurement is performed for the optimum case and the slice emittance is presented as a function of time together with the measured longitudinal profile of the bunch.

A slice width and a time scale are calibrated using a simulated single particle phase scan in the booster and the dipole current to momentum calibration. The slice width stays constant along the bunch and is equal for three measurements done with the off-crest booster phase of -30 degrees. It allows to recalculate a slice charge into a current.

100 pC bunch charge The first measurement was conducted with 100 pC with a laser spot of 0.18 mm (rms). As it follows from ASTRA simulations[1] the optimum slice emittance of 0.13 mm mrad is achieved with a laser spot size of about 0.13 mm. A simulated slice emittance of 0.16 mm mrad corresponds to the spot size of about 0.18 mm.

The average slice emittance value was measured versus the solenoid current (Fig. 2) using a fast measurement procedure (three slices, less points in the quadrupole scan) first to find the minimum value. Both curves, average emittance and peak current slice emittance, are rather flat at the level of 0.4 mm mrad. At lower solenoid currents emittance is measured significantly higher for the edge slices than for the central part of the bunch. It results in a higher average value although the central part emittance still tends to decrease. In the detailed measurement for $I_s ol = 384$A the central slices including the peak current slice have an emittance of 0.32±0.02 mm mrad. At the edges the emittance values are 0.54 mm mrad and 0.40 mm mrad. Results are shown in Fig. 3.

[1] all simulations consider a bunch thermal emittance formed by electrons emitted isotropically with an initial energy of 0.55 eV

230 pC bunch charge The measurement with the bunch charge of 230 pC was performed for the laser spot size of 0.3 mm. ASTRA simulation predicts a peak current slice emittance value of 0.26 mm mrad for the setup. The emittance optimum of 0.22 mm mrad for the bunch charge is obtained with a laser spot size of 0.22 mm.

The same procedure was followed as in the case of 100 pC. First the solenoid current was scanned and the results are shown in Fig. 4. Both curves show similar behavior and the current of 382 A was chosen for a detailed scan (Fig. 6). It resulted in the peak current slice emittance of 0.52±0.04 mm mrad.

500 pC bunch charge A laser spot size of 0.3 mm was used for this measurement. ASTRA simulations results in a peak current slice emittance value of 0.38 mm mrad. The laser spot diameter corresponds to the optimum case in the simulations.

The same measurement procedure with fast solenoid current scan (Fig. 5) and a detailed measurement for the optimum current of 390 A (Fig. 6) were applied. The peak current slice emittance measurement results in a value of 0.68±0.05 mm mrad.

1000 pC bunch charge The measurement was done using the laser spot diameter of 0.3 mm. In ASTRA simulations the charge extraction is space charge limited up to ∼0.9 nC within 21-22 ps at the gun gradient of ∼60 MV/m. Hence

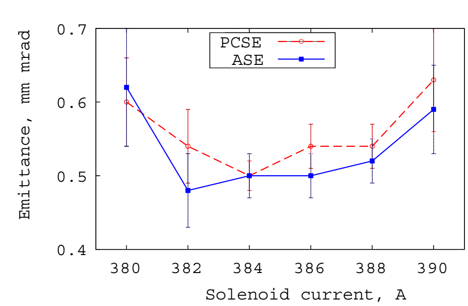

Figure 4: Slice emittance solenoid scan with 230 pC bunch charge.

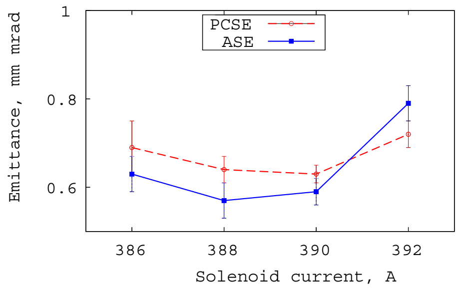

Figure 5: Slice emittance solenoid scan with 500 pC bunch charge.

no estimate for this case was done.

Slice emittance was measured for the solenoid current of 392A obtained from projected emittance optimization. The projected emittance value was measured to be 0.94 mm mrad. The peak current slice emittance value obtained in this measurement is 0.88±0.05 mm mrad.

0.3 mm laser spot size summary Figure 6 contains the measurements with 0.3 mm laser spot size. Each bunch charge detailed measurement is presented for the solenoid current where the slice emittance minimum was observed in the fast measurement scan. On the top plot the longitudinal profiles are shown. The bottom plot shows slice emittance versus time within the electron bunch. Fully optimized projected emittance values measured for 1 nC and for 0.25 nC with a laser spot size of 0.3 mm are indicated in the left part of the plot. Table 1 represents the peak current slice emittance results.

Plotting the emittance of the peak current slice versus its

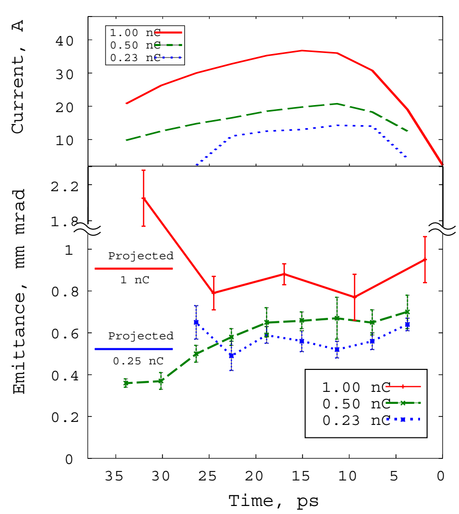

Figure 6: Summary: results of detailed slice emittance measurements for different bunch charges. Measured projected emittance levels are indicated for 1 nC and for 0.25 nC.

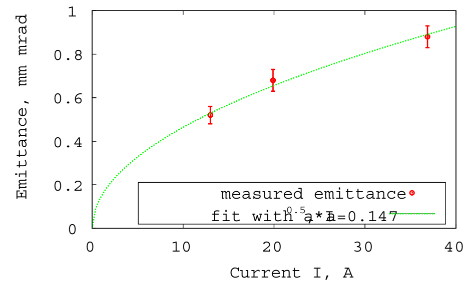

Figure 7: Summary: emittance of the peak current slice as a function of the slice current.

charge one obtains Fig 7. The solid line represents the data fit with square root function. The electron beam brightness along the line is constant if transverse emittance is symmetric in both planes and the slice duration is the same. As one can see the experimental results are lying on the line within the error bars.

Table 1: Peak Current Slice Emittance Measurement Results

Q_{bunch}, nC	I_{slice}, A	ε_{slice}, mm mrad
0.23	13.0	0.52±0.04
0.5	19.9	0.68±0.05
1.0	36.9	0.88±0.05

CONCLUSIONS

The results presented in this paper give slice emittance values measured for different bunch charges ,each charge for a single laser spot size at the cathode. The slice emittance is the same within the error bars as the fully optimized measured projected emittance. Slice emittance versus current is lying on a constant electron beam brightness curve. Further optimization with the laser spot size at the cathode is required to find the minimum slice emittance values.

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