SYNCHROTRON RADIATION MONITOR FOR ENERGY SPECTRUM MEASUREMENTS IN THE BUNCH COMPRESSOR AT FLASH

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Abstract

Longitudinal bunch compression in magnetic chicanes is used at the Free-electron LASer in Hamburg FLASH for the generation of ultra-short electron bunches. A Synchrotron Radiation monitor (SRM) has been installed behind the third dipole of the first bunch compressor to measure the energy and energy profile of the dispersed bunches. An intensified CCD camera records the emitted SR in the visible and enables one to select single bunches out of a bunch train. The performance of the system has been tested for different accelerator settings. The setup serves as a test bed for the European X-ray Free Electron Laser.

INTRODUCTION

The imaging of Synchrotron Radiation (SR) emitted in bending magnets and wigglers has been utilised successfully for many years in electron and proton storage rings for beam position, beam size and emittance measurements [1]. In short wavelength free-electron lasers (FELs), longitudinal bunch compression is used to produce ultra-short electron bunches with high peak currents. A common scheme for bunch compression, which is foreseen in most of the proposed FEL facilities, is based on off-crest acceleration in combination with magnetic chicanes. These magnetic chicanes are excellent candidates for the imaging of SR in the linear accelerator that drives the FEL.

A synchrotron radiation monitor (SRM) has been installed in the dispersive section of the first bunch compressor BC2 at FLASH. A sketch of the FLASH injector is shown in the top layer of Fig. 1. The rf photo-cathode gun is directly followed by the super-conducting 1.3GHz accelerating module ACC1 which accelerates the electrons to a beam energy of typically 130 MeV. A quadrupole triplet focuses the electron beam into the 4-dipole chicane BC2 and produces a beam waist between the third and fourth dipole.

The large horizontal aperture of the flat vacuum chamber (200 mm $\times$ 8 mm cross section) allows one to operate BC2 at bend angles in the range 15° - 21°. The lower part of Fig. 1 depicts the geometry of BC2 and beam trajectories for bend angles of 16°, 18° and 20°. For optimum bunch compression, the module ACC1 is operated at about 9° off-crest acceleration. The inset of Fig. 1 shows the top view of a particle distribution at the entrance of the third dipole, modelled with the particle tracking codes ASTRA and elegant for 9° off-crest acceleration. The horizontal beam widths is completely dominated by the horizontal dispersion which is about 300 to 390 mm for bend angles in the range 16° - 20° [2]. The tail with higher beam energy takes an inner trajectory and catches up with the head. The imaging of the transverse beam distribution reveals information on the longitudinal energy distribution, t-y correlated beam tilts and the transverse beam size and position as is reported in this paper. The spectral distribution emitted by a single particle with an energy of 130 MeV has been calculated with Schwinger's equation and is shown for 3 bend angles in Fig. 2.

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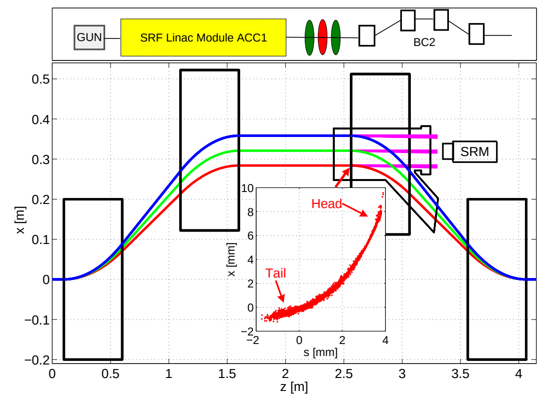

Figure 1: Top: Sketch of the FLASH injector. Bottom: Geometry of BC2 and beam trajectories for bend angles of 16°, 18° and 20°. Inset: Top view of particle distribution at 9° off-crest acceleration in module ACC1 (simulation).

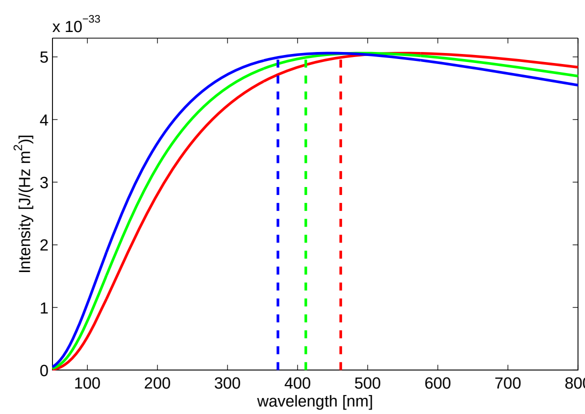

Figure 2: Spectral distribution of the SR calculated with Schwinger's equation for bend angles of 16°, 18° and 20° in BC2. Dashed lines indicate the corresponding critical wavelengths.

SR MONITOR SETUP

A new vacuum chamber with a special SR port was installed at the third dipole of BC2 in October 2006. The port houses a flat, Ag-coated laser mirror (Linos, 20 mm $\times$ 30 mm), which deflects the SR emitted at the entrance of the third dipole downwards by 90°. The SR is then imaged by a commercial lens (Sigma, f = 180 mm) and recorded by a gated, intensified CCD camera (PCO, dicam pro) which are located in the accelerator tunnel at a distance of about 1.25 m to the source point. The imaged source size is 10 cm $\times$ 8.2 cm which gives a pixel resolution of 80 μm per pixel. Both the deflecting mirror and the camera system are mounted on movers which can be moved perpendicular to the linac axis to be able to adjust to the electron beam trajectory for different bend angles. The lens is also equipped with a stepper motor to be able to change the lens focus remotely. Figure 3 shows the measured vertical (rms) beam size versus the lens focus. By adjusting the gate and delay of the camera timing, single bunches can be recorded out of a bunch train.

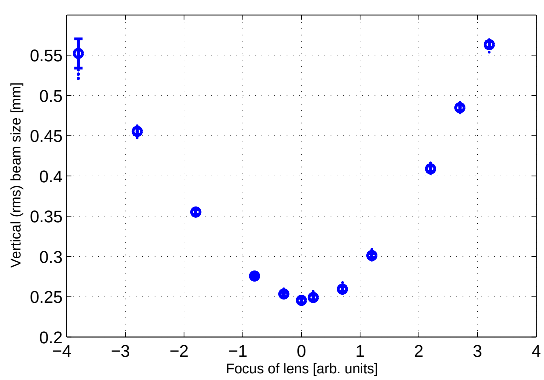

Figure 3: Measured rms beam size vs. lens focus.

A BG39 filter (Schott) in front of the lens was used to cut off wavelengths above 600 nm. The diffraction-limited resolution can be estimated by $0.61(\lambda/\theta)$ for a round aperture, where θ is the half opening angle of the SR. In addition, the depth of field and finite arc length from which the SR is emitted determine the total resolution [3]. The aperture of the lens should be adopted to the opening angle of the SR: A smaller aperture would increase the diffraction and, on the other hand, a larger aperture degrades the resolution due to an increase of the depth of field and finite arc that is imaged. The total resolution has been calculated for 3 f-numbers (5.6, 8, and 11) of the lens and are shown in Fig. 4. The vertical (rms) beam size was measured for these settings. The real beam size can be estimated from particle tracking simulations and beam optics to be 230 ± 20 μm. This value was subtracted quadratically from the measured beam sizes and the result is included in Fig. 4 and in good agreement with the analytical estimates. All measurements presented in the remainder were carried out with a focus and f-number that gave the best resolution of $\sim 90\mu$m.

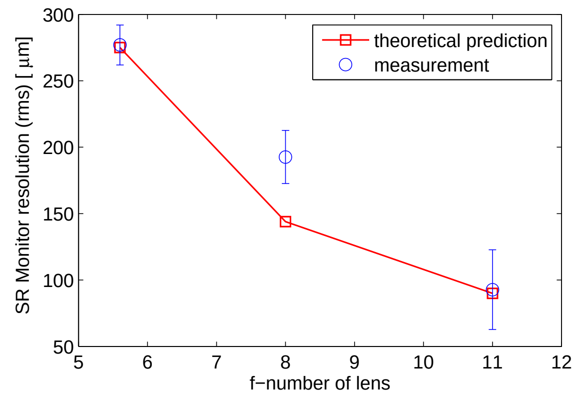

Figure 4: Resolution of SR monitor (for further explanation see text).

Energy Calibration

An energy scale can be established by scanning the dipole current - all dipoles are driven by one power supply - and recording the horizontal beam position. The result of such a scan is shown in Fig. 5 and the linear fit gives a calibration constant of 35.1 pixel/% relative energy deviation.

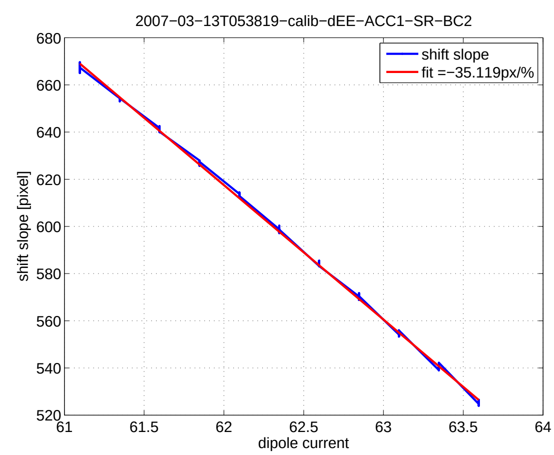

Figure 5: Energy calibration of SR monitor.

Module ACC1 Phase Scan

The left part of Fig. 6 shows the transverse beam distributions measured for 2°, 4°, 6° and 8° off-crest acceleration in module ACC1. The corresponding horizontal beam profiles for which the x axis has been converted to an energy axis are shown in the right part of Fig. 6. As can be seen, the profile first develops a tail towards smaller beam energies until it becomes more symmetric again and starts to shift completely to smaller beam energies. At 8° off-crest phase, which is well within the range for FEL SASE operation, the peak-to-peak energy spread is about 3%. For stable SASE operation it is important to measure and control the rms energy stability to an accuracy better than 10^{-4} which is about 1/300 of the full energy spread.

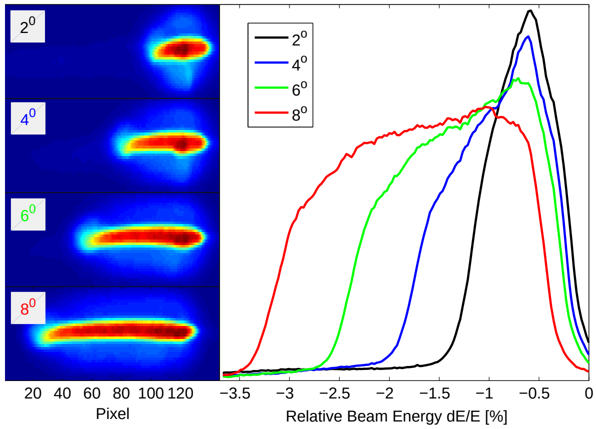

Figure 6: Transverse beam distributions and profiles for 4 off-crest acceleration phases of module ACC1.

JITTER MEASUREMENTS

An energy jitter transforms into a horizontal position jitter via $\Delta x = R_{16}\Delta E/E$ (1st-order transport theory). A relative energy jitter of less than $1 \cdot 10^{-4}$, which corresponds to a beam position jitter of about 30 μm, is desirable for an operation with a high beam arrival and peak current stability. Figure 7 shows the bunch-to-bunch energy and position stability recorded for the first bunch in a bunch train over a period of 120 s: the measured rms energy jitter is $2 \cdot 10^{-4}$ and the rms vertical centroid jitter is 10 μm.

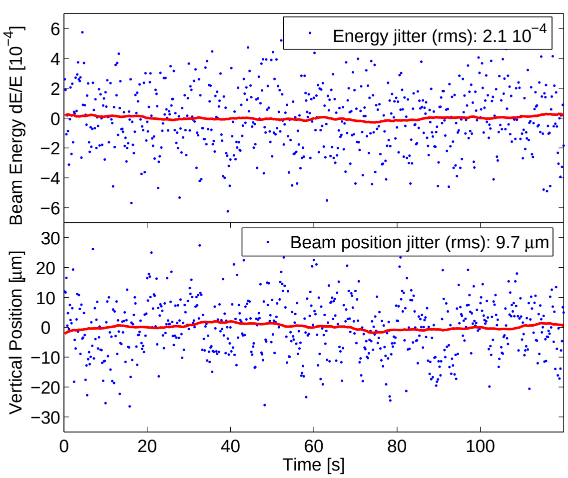

Figure 7: Single-bunch beam energy jitter measured during a SASE run at 9° off-crest acceleration in module ACC1.

By scanning the camera's trigger delay, the energy slope on the bunch train can be measured. This procedure has been used to crosscheck the intra-bunch train energy feedback of the low-level rf [4]. An energy jitter transforms also into a time jitter by $\Delta t = \Delta E/E \cdot R_{56}/c$ which can be calculated from the measured energy jitter $\Delta E/E$ and the knowledge of the longitudinal dispersion R_{56} [2]. A measurement synchronised with an electro-optical temporal decoding experiment located upstream of the FEL undulators has indicated that the main contribution of the timing jitter arises in BC2 [5].

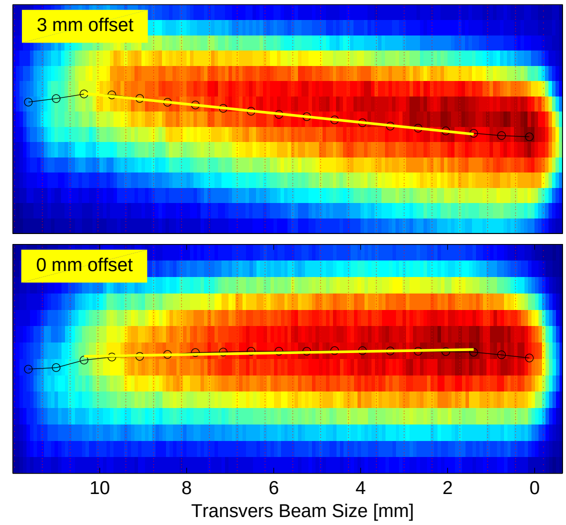

Figure 8: A vertical beam tilt is induced by an offset in the beam trajectory in module ACC1.

TILT MEASUREMENTS

Upstream of the first bunch compressor, where the electron bunches are rather long, careful steering through the accelerating module is important to avoid longitudinal tilts of the beam due to wakefields, coupler kicks or dispersion generated in the cavities. In a test measurement, corrector magnets were used to generate an offset of 3 mm at the exit of module ACC1. As the electron beam is streaked out horizontally in BC2 due to dispersion, a longitudinal t-y correlation transforms into a transverse x-y correlation. The transverse beam distributions for the cases with and without an offset are compared in Fig. 8. The horizontal beam distribution was cut into 19 slices and the mean vertical beam position has been calculated (black dots). A linear fit (solid yellow line) was used to calculate a beam tilt of about 30 mrad.

REFERENCES

[1] G. Kube, "Review of Synchrotron Radiation based Diagnostics for Transverse Profile Measurements", MOO1A03, this conference.

[2] P. Castro, "Beam trajectory calculations in the bunch compressors of TTF2 ", DESY Technical Note 03-01, April 2003.

[3] A. Hofmann and F. Méot, "Optical Resolution of Beam Cross-Section Measurements by Means of Synchrotron Radiation", Nucl. Instr. and Meth. **203**, 1982, 483-493.

[4] H. Schlarb *et al.*, "Beam Based Measurements of RF Phase and Amplitude Stability at FLASH", WEPC01, this conference.

[5] A. Azima *et al.*, to be published in Phys. Rev. ST-AB.