Beam Dynamics Experiments and Analysis on CSR Effects at FLASH

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Abstract

The Free Electron Laser in Hamburg (FLASH) is a linac driven SASE-FEL in the vacuum-ultra-violet (VUV) wavelength range [1]. High peak currents are produced using magnetic bunch compressor chicanes. In these magnetic chicanes, the energy distribution along an electron bunch is changed by the emission of Coherent Synchrotron Radiation (CSR). Energy changes in dispersive sections lead to transverse displacements along the bunch. Measurements of CSR induced transverse displacements are presented and compared with simulations.

INTRODUCTION

The peak current of an electron bunch emitted by an rf gun is about 50-100 A. For SASE operation at FLASH, the necessary peak currents of 1-3 kA are reached using longitudinal bunch compression. A two stage bunch compression system with the magnetic chicanes BC2 and BC3 is employed (see Fig.1).

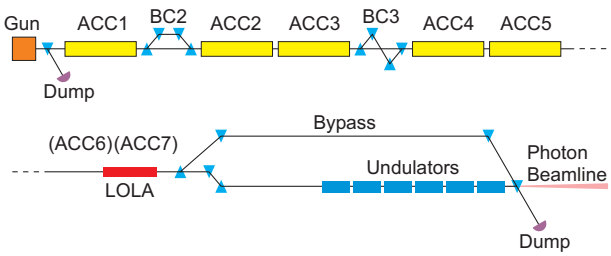

Figure 1: Sketch of FLASH. The blue triangles indicate dipole magnets, the yellow boxes TESLA acceleration modules.

A transverse deflecting rf-structure (LOLA) [2] is used to take ”top view” pictures of the bunch - the projection into the longitudinal-horizontal plane. Thus, centroid shifts along the bunch, for instance caused by CSR fields, can be observed.

However, other forces like space charge cause transverse shifts of beam centroids as well. For an undisturbed measurement of CSR effects, space charge effects have to be reduced. To that purpose, we over-compress the bunch. The longitudinal energy correlation (chirp) introduced in the module ACC1 is chosen to reach minimum bunch length and a peak current beyond 2 kA towards the end of the second magnet in the BC2 chicane. The bunch will exit the chicane roughly with its incoming length of about 2 mm, corresponding to about 50 A peak current. The integrated effect of space charge from the exit of BC2 to LOLA is then small compared to the centroid offsets caused by CSR.

MEASUREMENTS AND ANALYSIS

For our measurements, we vary the ACC1 phase and keep ACC2/3 on crest. The expected CSR effects are created during over-compression in BC2. Downstream, the transverse deflecting rf structure is passed at the zero-crossing phase. The particles are kicked transversely with a strength proportional to their longitudinal offset to the bunch center. The bunch is thus tilted and its longitudinal-transverse projection is observed on a screen.

Fig.2 shows a LOLA measurement. The red curve shows the longitudinal beam profile, the white dashed lines indicate the fwhm points.

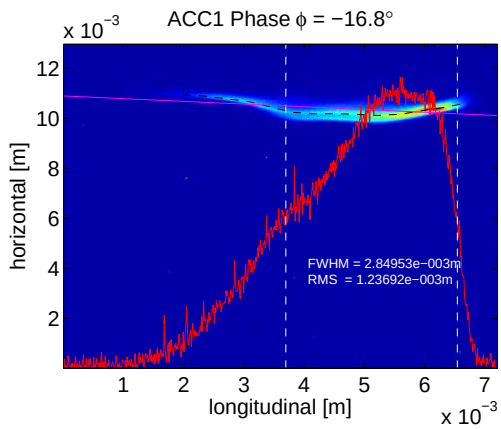

Figure 2: An example of a LOLA measurement. Longitudinal charge profile (red line), fwhm and rms bunch length are shown.

Fig.3 shows measured bunch length at LOLA as a function of the ACC1 phase as well as simulation results. The measured bunch length agrees well with the simulation downstream of BC3, as it should. The calculated bunch length downstream of BC2 (green line) is, for small phase offsets, longer, since the bunch is further compressed in BC3. At about 12 degrees, the bunch is fully compressed in BC2. Above 12 degrees, the bunch is over-compressed, the chirp changes its sign and the BC2 bunch length is shorter.

Fig.4 shows measured longitudinal-horizontal projections of the bunch for different compression scenarios. In the uppermost picture, the ACC1 phase is on crest, no com-

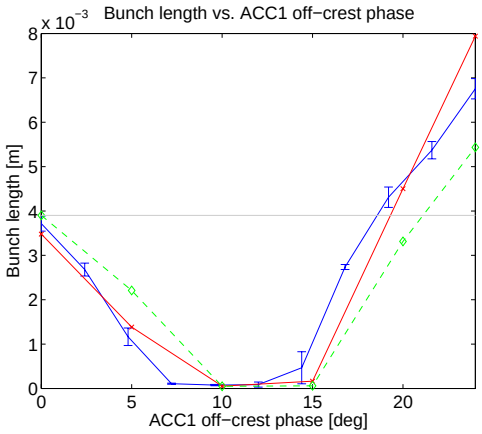

Figure 3: Measured fwhm bunch length at LOLA (blue line) are compared with simulations. Red line: calculated bunch length at LOLA. Green line: calculated bunch length after BC2.

pression occurs and the horizontal centroid positions line up straight. Close to full compression (middle picture), the beam is heavily distorted by CSR and space charge effects. This is understood and simulated [3], but would be very challenging as a starting point for quantitative CSR studies.

The bottom picture shows the over-compressed case, where the space charge effects are negligible and strong CSR occurs only in BC2. The beam centroids are still on a smooth line. Its shape and sag will be compared with simulations in the next paragraph.

Fig.5 reflects the bunch shape changes described above in plotting the peak to peak bunch centroid shift as a function of ACC1 phase offset.

Comparison with Simulations

Tracking calculations were done to simulate longitudinal-horizontal beam projections at LOLA. Beam transport through ACC1 was calculated with the space charge tracking code ASTRA [4]. After ACC1, wake fields are applied as a discrete effective kick [5]. The tracking code CSRTrack [6] is used to simulate CSR effects in BC2. The 1D projected model is used [7]. The long bunch length after BC2 in the over-compression case allows the simulation of the beam transport to LOLA by a first order matrix.

To compare the simulated longitudinal slice centroid positions with the measurements these data have to be extracted from the measured distributions. In a first step each distribution is divided into slices along the longitudinal axis. The horizontal charge profiles of these slices are then calculated. Gaussian fits are used to determine the center of each profile. An example for the resulting centroid curve is the dashed black line in Fig.2.

At big ACC1 phase offsets, the bunches start to be tilted

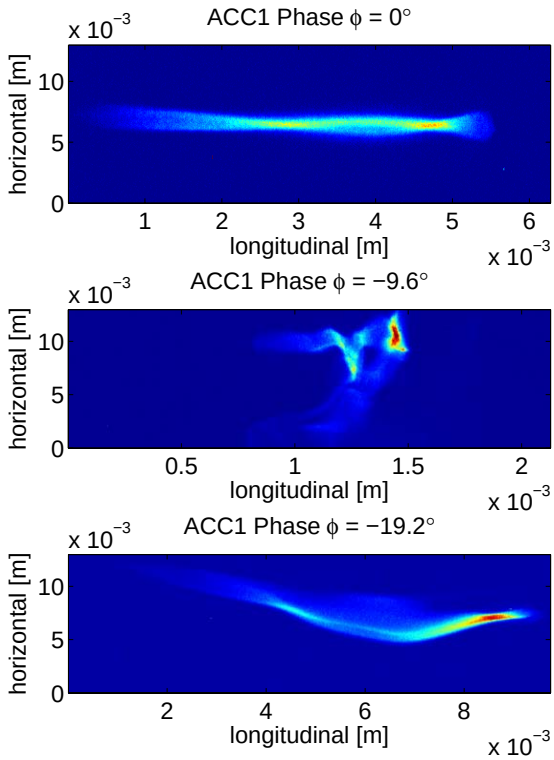

Figure 4: Measured top view for different ACC1 phase offsets. Top: no compression. Middle: near full compression. Bottom: over-compression.

on the screen. The cause of this is under investigation. The linear correlation as indicated by the magenta line in Fig.2 is subtracted from the centroid curve.

For error analysis, a series of pictures is taken for each ACC1 phase setting. The different centroid curves are

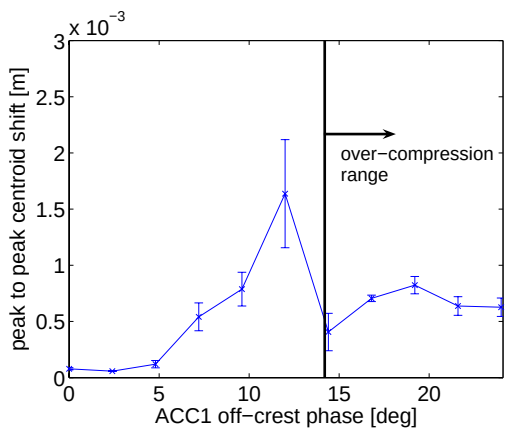

Figure 5: The peak to peak centroid shift along the bunch is plotted vs. the phase offset in ACC1. Phase range used for the experiment: 14 to 24 degrees.

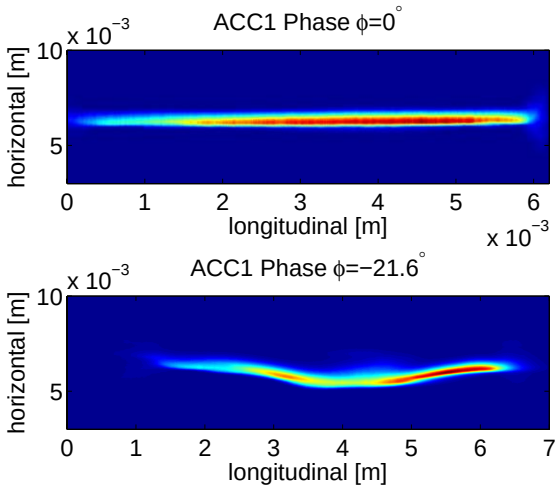

Figure 6: Simulated top view after BC2 for different ACC1 phase offsets. Top: no compression. Bottom: over-compression.

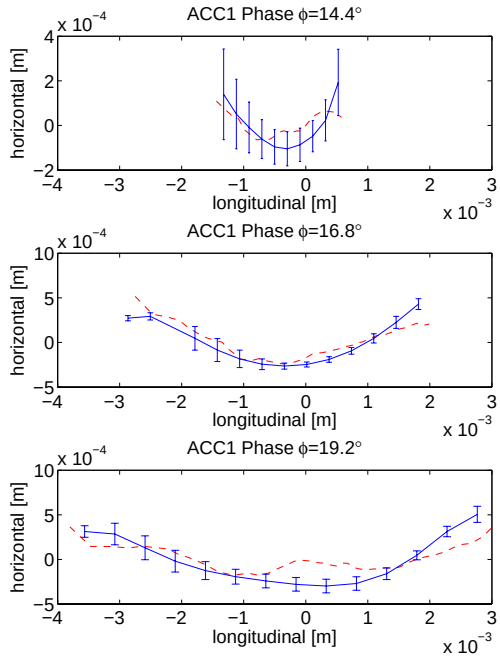

Figure 7: Experimental centroid curves are compared with simulated data. The blue lines represent the data taken with LOLA and the dashed red curves represent the results of simulations. Linear correlations are subtracted.

aligned to their individual centre of mass. The curves are then fitted with a polynomial and their mean value and rms spread are calculated for different longitudinal positions. In Fig.7, these results are compared with the tracking calculations.

CONCLUSION AND OUTLOOK

CSR effects in the first bunch compressor chicane in FLASH were observed using the transverse deflecting rf-structure LOLA.

The offsets of the centers of the longitudinal bunch slices for different over-compression scenarios were measured and compared with simulation calculations.

Next steps in the experimental program are studies of slice emittance growth due to CSR effects and dependences on bunch charge and beam optics in the chicanes [8].

The observed beam tilt will be investigated to improve both SASE operation and CSR measurements.

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