BEAM TILT AT THE FIRST BUNCH COMPRESSOR AT FLASH

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Abstract

At the Free Electron Laser in Hamburg (FLASH), when the electron beam is accelerated some degrees off-crest in the first accelerator module as during SASE operation, a correlation between the longitudinal position and the beam energy is induced. Between the second and the third dipole of the first bunch compressor (BC2), the horizontal beam position correlates linearly with the beam energy. With additional vertical dispersion, the beam is tilted in the x-y plane in this region (see Fig. 1), thereby increasing the projected vertical emittance. A systematic study of how vertical dispersion tilts the beam at the BC2 and causes an increase of the vertical emittance is presented here. The dispersion is generated by applying vertical trajectory bumps through the first accelerator module.

INTRODUCTION

The FEL process requires a high quality electron beam. Small beam sizes and emittances are needed in the undulator section, for which both optimization in the injector and beam quality preservation along the linac are required.

In the injector area, the laser, the RF gun, the solenoid, and the electron trajectory have to be adjusted and controlled to have optimal initial conditions. This paper presents studies on how vertical trajectory deviations in the injector section turn into dispersion and degrade the beam quality at FLASH.

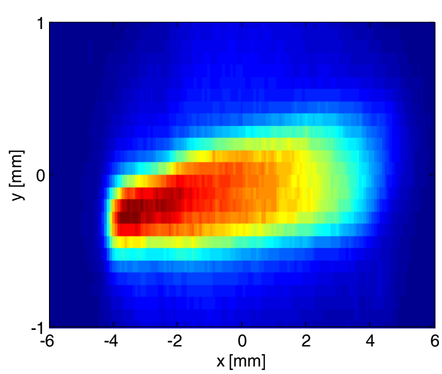

Figure 1: Example of x-y tilted beam. The image is taken with the SR (Synchrotron Radiation) camera of BC2.

FLASH

FLASH, based on the TESLA Test Facility (TTF), is a user facility at DESY and a pilot facility for the XFEL and the International Linear Collider (ILC) projects [1]. It generates SASE-FEL radiation with a wavelength ranging from the vacuum ultraviolet to the soft x-ray regime. FLASH demonstrated SASE operation at a wavelength of 32 nm in 2005, at 13 nm in 2006 and at 6.5 nm (design value) in 2007.

A schematic layout of FLASH is shown in Fig. 2. Electron bunches are generated in a laser-driven RF gun with a nominal bunch charge of 1 nC. Electron beam energy can be increased up to 1 GeV in six accelerating modules, each of them containing eight superconducting cavities. Electron bunches are compressed in two bunch compressor chicanes. An energy collimation section protects the undulator magnets against radiation damage. Electrons follow the SASE process in the undulator, a section consisting of six segments with a length of 4.5 m each.

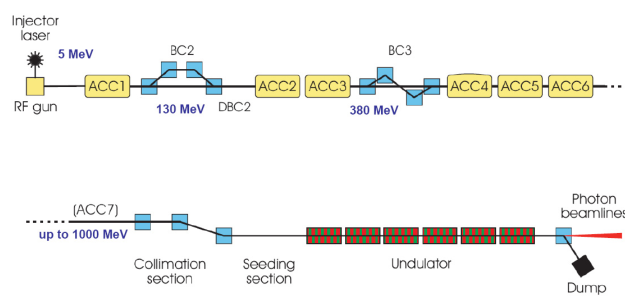

Figure 2: Schematic layout of FLASH (not to scale).

MEASUREMENTS

Figure 3 shows a sketch of the experiment. Six different vertical trajectory bumps were applied through ACC1, which was running 9 degrees off from on-crest acceleration. Two vertical steerers upstream of ACC1 were used to set the bump (V1GUN and V2GUN) and two correctors downstream of the module to close the bump (V10ACC1 and V1UBC2). The beam charge was 0.62 nC.

Table 1 shows the amplitudes of the bumps at BPM9ACC1, which were derived from the current of the steerers. For the reference case (no bump, zero current of the gun steerers) the absolute BPM reading at 9ACC1 was -2.8 mm. Maximum bump amplitudes (about 5 mm in each direction) were limited by steerer current and focusing in ACC1.

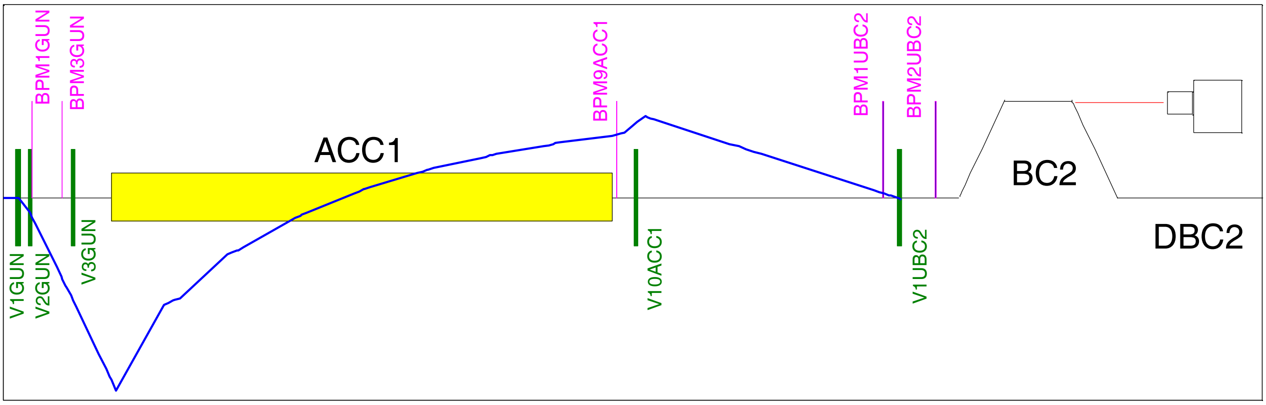

Figure 3: Sketch of the beam tilt experiment. Trajectory bumps are excited with gun steerers V1/2GUN and closed with V10ACC1 and V1DBC2. It should be noted the strong focusing effect in the first cavity of ACC1.

Table 1: Amplitude at BPM9ACC1 for All the Bumps

Bump	Relative bump amplitude [mm]
Reference (y = -2.8 mm)	0.0
1	-5.3
2	-3.1
3	-2.0
4	1.7
5	3.5
6	4.6

For each bump, the dispersion from ACC1, the beam tilt at the bunch compressor, and the projected emittance downstream of BC2 were measured.

Dispersion

The dispersion measurement requires knowledge of the orbit for different beam energies, which are obtained by changing the gradient of the accelerator module. More details about dispersion measurement at FLASH can be found in [2].

The measurement results are shown in Fig. 4. The horizontal dispersion (upper plot) was small and constant for the different bumps. Concerning the vertical plane, the measured dispersion for the reference case was not zero, which indicates that the beam traveled vertically off-axis through the module for the reference case.

Beam Tilt

The beam tilt was measured using the SR monitor installed behind the third dipole magnet of BC2 [3]. Per each point, the beam image was obtained by averaging twenty images of consecutive shots and subtracting the background. To obtain the beam tilt, the image of the region of interest was divided into slices and the center of each slice was determined. Finally, a linear fit to the slice centers gave the beam tilt. For the reference case, the measured tilt was 0.7 degrees. Measurements gave a slope of -0.24 deg./mm [tilt/bump amplitude].

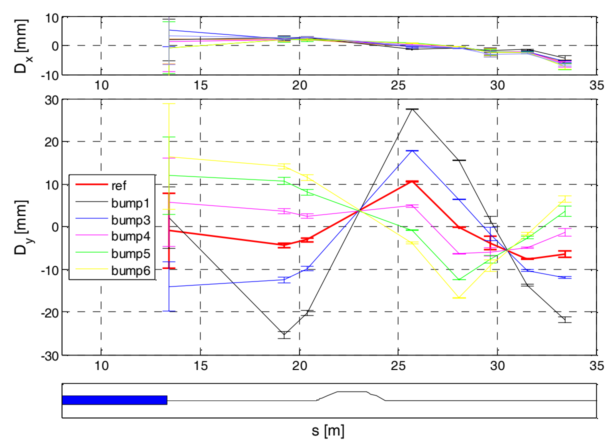

Figure 4: Dispersion measurements. Upper plot: horizontal dispersion. Middle plot: vertical dispersion.

Projected Emittance

For the emittance determination, the transverse beam distribution is measured at 4 OTR (Optical Transition Radiation) monitors mounted into a FODO lattice downstream of BC2. Using the transport matrices between the different measurement points, the emittance and the Twiss parameters are obtained by fitting the measured beam sizes. A detailed description of the emittance measurement procedure is in [4].

The measurement results are shown in Fig. 5. The emittance was generally bigger in the horizontal plane due to collective effects in the horizontal bunch compressor (i.e. due to CSR effects). Horizontal emittance remained approximately constant for the different bumps – between 3.5 and 4 µm. Vertical emittance increased for negative bump amplitudes at BPM9ACC1 (from 2.3 µm up to 3.7 µm) and decreased for positive bump amplitudes (down to 1.8 µm).

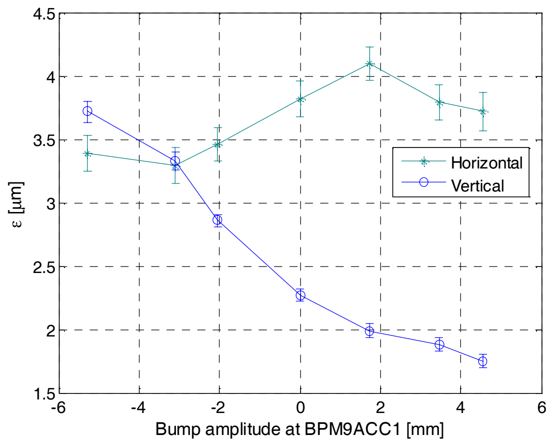

Figure 5: Measured horizontal and vertical emittances.

In the reference situation (without steering in the gun section) the dispersion and the beam tilt were not zero and the emittance was not optimal. This indicates that the beam exited the gun with a non-optimal vertical trajectory.

SIMULATIONS

Simulations were done with the program *elegant* [5]. The settings for the steerers V1/2GUN were taken from the measurements and the currents for V10ACC1 and V1UBC2 were chosen to close the bump. A 10^5 particle distribution obtained from ASTRA [6] for standard conditions was used as an input for elegant. Wakefields and coupler kicks of the accelerator module ACC1 were taken into account. The effects of the wakefields and coupler kicks on the simulation results were almost negligible.

Two different initial conditions were considered in the simulations:

- Ideal on-axis trajectory coming from the gun.
- An initial vertical trajectory offset of 3.0 mm at the exit of the gun.

Comparison between Measurements and Simulations

The simulations with an initial vertical offset of 3 mm reproduce the absolute orbit and dispersion for the reference case. For the simulations without initial offset, the initial trajectory and dispersion are obviously zero.

Figure 6 shows a comparison between the simulated and the measured beam tilt as a function of the bump amplitude. Measurements and both simulations have the same slope *tilt/bump amplitude*. Simulations without initial trajectory offset give no tilt when there is no bump.

In the simulations with the initial offset, the tilt is 0.8 degrees - a value which reproduces well the measurement results.

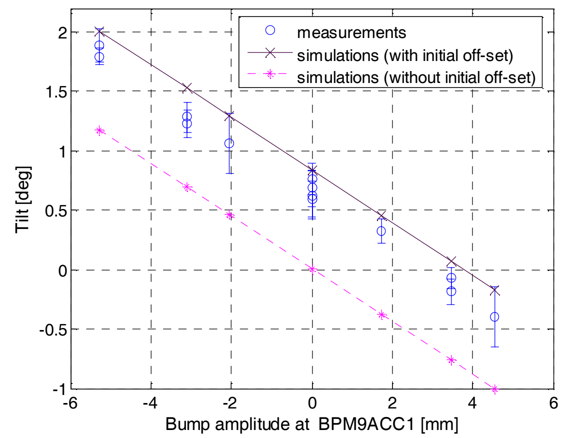

Figure 6: Simulated and measured beam tilts.

Figure 7 shows a comparison between measured and simulated vertical emittance increase for all the bumps. The simulations with the initial trajectory offset reproduce well the measurements (i.e. emittance increase for negative bumps and decrease for positive bumps). Simulations without an initial offset give optimal emittance for a zero bump amplitude.

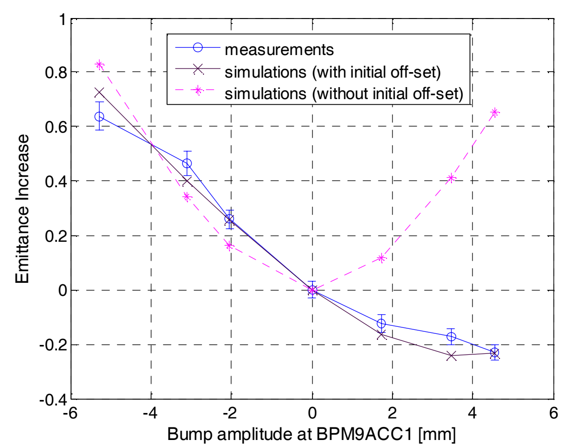

Figure 7: Simulated and measured vertical emittance increases.

CONCLUSION

Vertical dispersion degrades the beam quality in the injector section of FLASH when the first accelerator module is running off-crest (as during FEL operation): the beam is observed tilted between the second and the third magnets of the bunch compressor and the projected vertical emittance is increased.

One would expect no beam tilt and minimum vertical emittance with gun correctors off. However, in this case the beam had a tilt of 0.7 degrees and suboptimal emittance. Negative orbit bumps deteriorated even more the beam, while the best beam conditions were fulfilled for the biggest positive bumps.

These results were reproduced in simulations assuming a vertical trajectory offset downstream of the gun (i.e. after the solenoid field) of 3 mm. The required steering in the gun section to improve the beam quality was counteracting a vertical kick which is in accordance with a relative solenoid misalignment of about 300 µm.

Beam tilt measurements with the SR camera can be done parasitically and fast (a measurement averaged over 100 shots and subsequent analysis takes about half a minute). Therefore, the SR camera can be used in a convenient way to check and optimize the beam quality at the injector section of FLASH. Moreover, dispersion measurement from ACC1 can be used as a fast indicator for the alignment of the beam within the module.

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