ELECTRON BUNCH SHAPE MEASUREMENTS AT THE TTF-FEL

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Abstract

The TESLA Test Facility linac has been operated in the first half of 2002 with two bunch compressors to drive the TTF-FEL free electron laser. During this running period, SASE radiation with a wavelength around 100 nm has been routinely delivered to experiments. The longitudinal shape of the electron bunches is a crucial property of the electron beam: a peak current in the order of 1 kA is required to drive the SASE process with the given undulator design, transverse emittance, and energy spread. We report on measurements of the bunch length and shape for different operating conditions of the two bunch compressors.

INTRODUCTION

To drive the TTF-FEL free electron laser at DESY, excellent beam properties in the transverse and longitudinal planes are essential: a small transverse emittance in the order of a μm, a high peak current in the kA range, and a small uncorrelated energy spread below 0.1 %.[1] Optimized TTF beam parameters for the FEL runs are discussed in Ref. [2]. The saturation has been achieved in the VUV wavelength region (80 to 100 nm)[3], and SASE radiation has been routinely delivered to the experiments during several running periods in 2001 and 2002.

A sketch of the TTF linac is shown in Fig. 1. The electron source is a laser-driven RF gun with a Cs_2Te cathode. The RF gun section is followed by a booster, a standard TESLA 9-cell superconducting accelerating cavity operated at 11.5 MV/m. After the booster the beam energy is 16.5 MeV. The beam is accelerated by two 12 m long TESLA accelerating modules containing eight 9-cell superconducting accelerating structures each. After a collimation section, the beam is injected into the undulator modules with an energy of up to 300 MeV. Two magnetic chicane bunch compressors are installed: BC1 is downstream of the booster cavity, BC2 between the accelerating modules.

At the end of the last FEL run beginning of 2002, both bunch compressors have been used to shape the longitudinal charge distribution of the electron bunch. In the following, measurements of the longitudinal bunch shape using a streak camera for different settings of the two compressors are presented.

EXPERIMENTAL SET-UP

To measure the bunch distribution, we use synchrotron radiation emitted by the horizontally deflecting spectrometer dipole after the undulator (see Fig. 1). The optical part of the synchrotron radiation is guided by four flat aluminum mirrors to a streak camera situated outside of the accelerator tunnel. An achromat lens is used to focus the light onto the entrance slit of the camera. In order to reduce chromatic effects, a narrow-band wavelength filter is being used. [4] The data presented here are obtained using a filter of 500 $\pm$ 40 nm.

The streak camera (Hamamatsu FESCA-200 C6138) has an intrinsic resolution of 208 fs (FWHM) measured with a fs probe laser.[5] Only some data have been taken with the fastest streak speed of 20 ps/10.29 mm. Most of the the data presented here are obtained with the second fastest streak speed of 50 ps/10.29 mm. For this speed, the resolution is 200 fs (sigma) only. In the case of long uncompressed bunches, the streak speed of of 100 ps/10.29 mm was more suitable. The entrance slit is adjusted to be as small as required to obtain the best resolution. In most of the measurements the slit is between 20 μm and 40 μm, the latter has a better photon yield. For these slit sizes the intrinsic camera resolution is not significantly changed. The gain of the streak camera multi-channel plate has been adjusted in a way to maximize the signal but to avoid saturation effects.

A bunch signal with a jitter of about 50 ps served as a trigger for the streak.[6]

DATA ANALYSIS

For a given machine setting, several streak images have been recorded. The images are projected onto the time axis. In order to reduce the noise due to photon statistics, several single profiles (typically from five to ten) are overlayed. Due to the trigger jitter, the recorded images are not in the same time position. The shifting of the profiles for overlaying along the time axis is performed manually taking the leading edge of the profile as a reference. The average of the overlayed profiles is calculated. Since the bunch charge was stable during the measurement, a charge scaling of the profiles was not necessary. An example of nine overlayed profiles with the average profile superimposed is shown in Fig. 2.

All profiles shown in the following are averaged profiles, and scaled according to their peak intensity. The profiles have not been corrected for the resolution of the camera.

EXPERIMENTS AND RESULTS

The longitudinal electron bunch profile has been measured with different settings of the bunch compressors. Table 1 summarizes some design parameters. In all the measurements presented here, the beam was passing through BC2 with a deflecting angle of 18°. Nominally, the first

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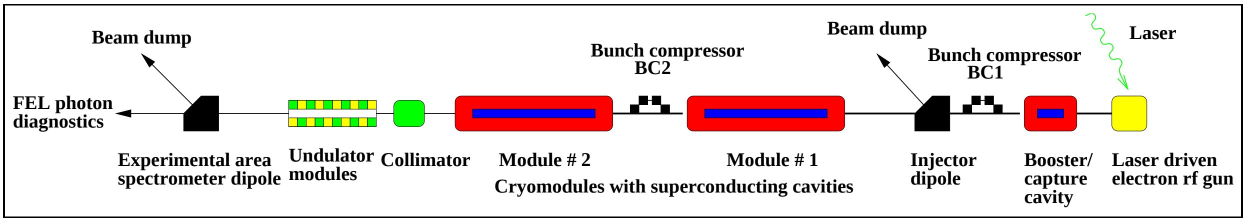

Figure 1: Schematic overview of the TTF-FEL linac phase 1 (not to scale). Beam direction is from right to left, the total length is 100 m.

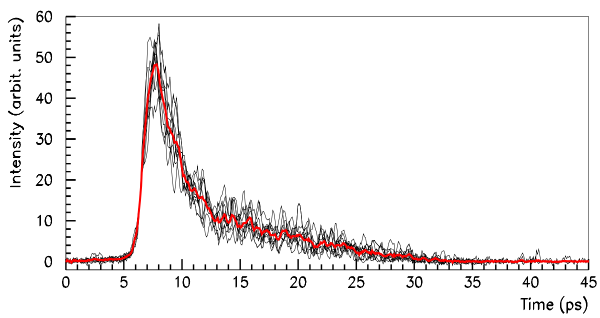

Figure 2: Several measurements of the same longitudinal beam profile. The average of the profiles is superimposed.

accelerating module (module 1) RF is dephased by 12° to obtain maximum compression. BC1 is either bypassed or used with two different deflecting angles: 24° and 30°. When BC1 is bypassed, the booster cavity RF is operated with a phase 10° off-crest corresponding to a minimum in energy spread. The RF phase of the RF-gun has always been nominal 40° from zero crossing. The second module is operated with on-crest acceleration.

Table 1: Some design parameters of the bunch compressors.

parameter	BC1	BC2
defl. angle (°)	22.5	18
R_{56} (mm)	88	180
max. disp. (mm)	-15	-346
compression ratio	2	4

For all settings, the general shape of the bunch is dominated by a sharp leading peak and a long tail. The smallest measured width of the peak is 600 ± 100 fs (sigma) and containes about 1/3 of the charge, yielding in a peak current of 1 kA.[2]

Figure 3 shows the effect of the booster phase and module 1 phase on the bunch shape. The beam passes through both compressors, BC1 is operated with a deflecting angle of 30°, BC2 with 18°. The bunch charge is about 1 nC.

In the upper plot, the module 1 phase is on-crest. The profiles are for the case of the booster at minimum energy spread (+10°, red), and at compression (+22°, blue). The compression effect of BC1 is only visible in the tails and in

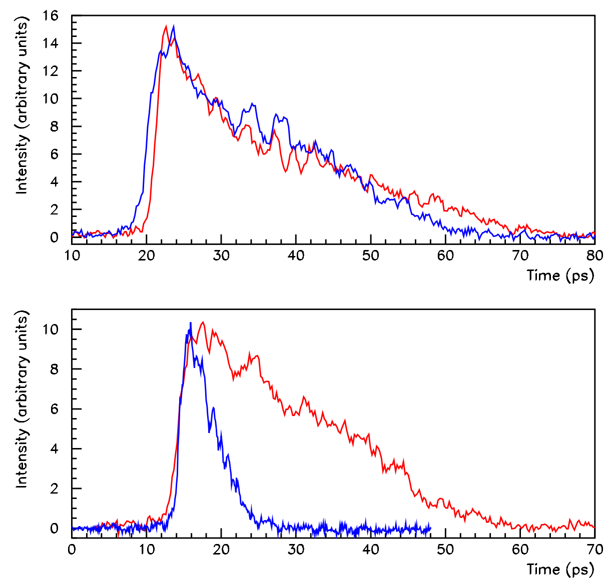

Figure 3: Average bunch profiles with both BC1 and BC2 in use (1 nC). *Upper:* Module 1 on-crest. Booster cavity phase corresponding to minimum energy spread, 10° off-crest (red), booster cavity phase at 22° off-crest (blue). *Lower:* Booster phase 22°, module 1 phase on-crest (0°) (red), module 1 phase in full compression (12°) (blue).

the calculated rms over the whole distribution.

The lower plot shows the effect of the module 1 phase: the module is on-crest as before (red), and with a phase of +12° corresponding to maximum compression (blue).

The compressing effect of BC2 is very clear (Fig. 3, lower plot). A similar behavior has been observed bypassing BC1 [4], as well as in our earlier measurements with a lower resolution camera[7], where the peak could not have been resolved.

The effect of the booster cavity phase is small (Fig. 3, upper plot). The aim of using BC1 is not to fully compress the bunch, but rather to *shape* the leading peak. We expect the precompression with BC1 to shorten the bunch before acceleration with module 1, and thus to reduce the curvature in the longitudinal phase space due to the RF. The reduced curvature leads – after compression with BC2 – to a larger and more gaussian peak and a shorter tail.

Figure 4 compares three bunch shapes, while the machine was lasing with SASE close to saturation. In one case, BC1 has been bypassed (red), in the other cases, BC1 has been set to compression (24° deflection), and tuned to keep the machine lasing. The booster phase is 25° (green) and 26.5° (blue). For all cases, the bunch charge was between 2.5 and 3 nC.

From the comparison it is clearly visible, that the pre-bunching with BC1 effectively widens the sharp peak and shortens the tail. The effect of this tailoring of the lasing bunch slice on the measured internal mode structure of the FEL radiation has been reported in [8].

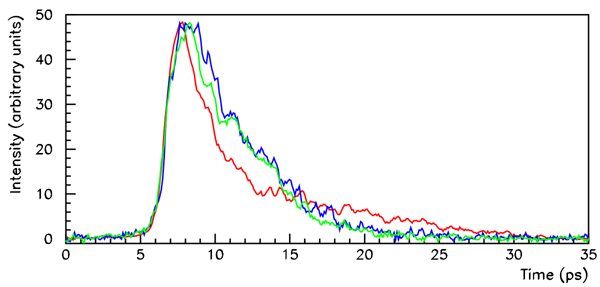

Figure 4: Average bunch profiles for settings, where the FEL was lasing. (a) BC1 is bypassed (red), (b) BC1 set to compression (24° deflection), booster phase at 25° (green) (c) and 26.5° (blue). Charge for all cases between 2.5 and 3 nC.

DISCUSSION AND CONCLUSION

We have measured longitudinal bunch shapes with different settings of the bunch compressors. The data show clearly a shape with a dominant leading peak of a cuurent of 1 kA and a long tail. The first bunch compressor BC1 is used as a pre-buncher to tailor the leading peak of the bunch profile. This peak shows up after compression with the second chicane BC2. It is actually the part or slice of the bunch which contributes to the SASE lasing process.

In this sense, TTF1 was able to influence the mode structure of the SASE FEL radiation by carefully adjusting phases and compression of BC1.

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