BUNCH LENGTH CHARACTERIZATION DOWNSTREAM FROM THE SECOND BUNCH COMPRESSOR AT FLASH DESY, HAMBURG

E. Chiadroni*, University of Rome "Tor Vergata", Rome, Italy
INFN LNF

Abstract

The longitudinal bunch distribution downstream from the second bunch compressor (BC3) of the Free electron LASer in Hamburg (FLASH) at DESY has been reconstructed using a Martin-Puplett interferometer to measure the autocorrelation of coherent diffraction radiation (CDR) in the sub-millimeter wavelength range.

Due to the low and high frequency suppression, introduced by the experimental apparatus, only a portion of the CDR spectrum participates to the reconstruction of the longitudinal bunch profile. The knowledge of the system frequency response is then a crucial requirement.

The experiment has shown a very good agreement with the expected (simulated) FLASH bunch profile. First experimental evidences of the non-intercepting nature of diffraction radiation (DR) diagnostics are also reported.

INTRODUCTION

When a bunch of electrons moves through an aperture in a metallic screen, each electron in turn emits radiation. The total radiation is the sum of all individual amplitudes, so that the DR spectrum depends on the bunch longitudinal dimension and, at wavelengths longer than the bunch itself, the emission is completely coherent. CDR is then a good candidate to measure the bunch length.

On one hand, a diagnostics based on DR has the great advantage of being non-invasive and non-intercepting. On the other hand, the main limitation of a frequency domain technique is the strong suppression of both high and low frequencies. The former one mainly due to the slit aperture in the diffraction radiator [1] and the vacuum pipe window transmission, while the latter one due to the finite size of the radiator [2], vacuum pipe window acceptance, reduced acceptance of both interferometer and detector, and low sensitivity of detectors at long wavelengths. A reliable calibration of the experimental apparatus and, in particular, of the detector frequency response is then mandatory [3], [4] in order to reduce the systematic error in the reconstruction procedure.

Furthermore, even though the analysis of the CDR spectrum gives an accurate characterization of the pulse shape, except for a phase factor, its reliability is strongly dependent on the bunch shape. Information on the missing phase can be retrieved by means of a Kramers-Kronig analysis [5].

* chiadroni@roma2.infn.it

EXPERIMENTAL SETUP

DR is produced by $380\ MeV$ electrons on the diffraction radiation target, tilted by 45^o with respect to the beam direction. It is extracted through a crystalline quartz window and by a series of mirrors parallelized and transported up to the interferometer (Fig.1), placed downstream from BC3 (Fig.2). The interferometer is shielded from electromagnetic noise and light by means of a metal blackened box and operates in air. The CDR signal is detected by Golay cell detectors. Interferograms have been acquired by means of a MatLab scan tool named MIST[1].

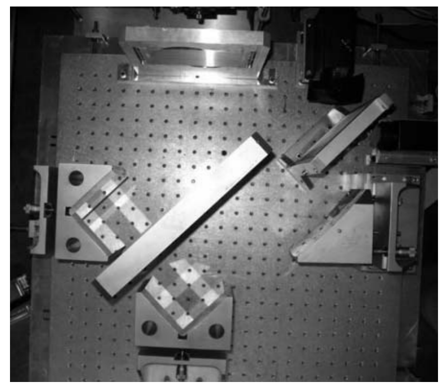


Figure 1: Martin-Puplett interferometer.

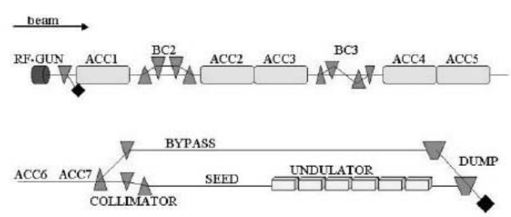


Figure 2: Sketch of the experimental apparatus.

Further details on the experimental setup and on the measurements can be found in [3].

THE BUNCH LENGTH MEASUREMENT

During the scan the signals from both detectors is recorded as function of the time shift between the two beams. The normalized difference interferogram is related to the power spectrum $I(\omega)$ by Fourier transformation. Since the measured spectra are affected by the entire apparatus frequency response, they have been corrected

[1] **M**artin-Puplett **I**nterferometer **S**can **T**ool written by Lars Fröhlich - DESY.

by its transfer function obtained by properly calibrating the system.

The radiation emitted by a bunch of N electrons might be dominated by incoherent or coherent emission, depending on the bunch length. Let I_{sp} be the spectral intensity of the single electron, the spectrum of the electron bunch is then given by

$$I(\omega) = I_{sp}(\omega)[N + N(N-1)F(\omega)] \tag{1}$$

where $F(\omega)$ is the electron bunch form factor which, in case of small observation angles, can be expressed in terms of the 1D longitudinal distribution function of particles in the bunch, $S(z)$:

$$F(\omega) = \Big| \int_{-\infty}^{\infty} dz S(z) e^{i\frac{\omega}{c}n} \Big|^2 \tag{2}$$

$S(z)$ is then determined by anti-transforming $\sqrt{F(\omega)}$, whose missing information on the phase is retrieved applying the Kramers-Kronig relation [5]

$$\psi_m(\omega) = -\frac{2\omega}{\pi} \int_0^{\infty} d\omega' \frac{\ln[F(\omega')/F(\omega)]}{\omega'^2 - \omega^2} \tag{3}$$

The bunch density distribution is finally obtained as

$$S(z) = \frac{1}{\pi c} \int_0^{\infty} d\omega F(\omega) \cos\left[\psi_m(\omega) - \frac{\omega z}{c}\right] \tag{4}$$

From simulations, supported by time domain measurements [6], the FLASH bunch profile is predicted to have a very sharp, asymmetric peak and a long tail, due to the non-linear energy-phase correlation introduced by off-crest acceleration.

Both the high and low frequency cut off result in a more complicate reconstruction of the bunch profile, in particular for FLASH-like ones, where the sharp peak, which highly contributes to the FEL lasing, contains large high frequency components.

MEASUREMENT RESULTS

Bunch Length Dependence on $ACC2-3$ Phase

Four interferograms have been taken by keeping fixed the $ACC1$ accelerating phase at the on-crest value and varying the $ACC2-3$ phase around the maximum compression value found with a phase scan at $12\ deg$. For convenience, the phase corresponding to the maximum compression is arbitrarily set at $0\ deg$. The energy measured at the exit of the third accelerating module is $380\ MeV$. Measurements were performed with low charge, $0.3\ nC$, and 1 bunch because of the peculiar Golay cell response [3].

The comparison between the normalized difference interferograms (Fig.3) shows a dependence of the curve width on the compression phase. The longer the bunch, the profile gets smoother and closer to a Gaussian distribution, resulting in the merging of the side minima with

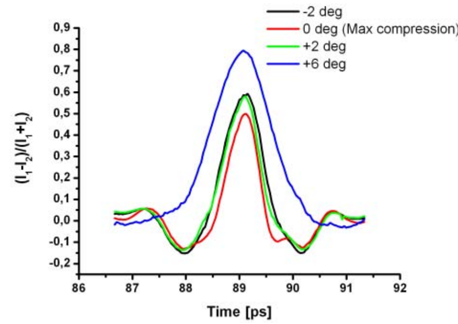
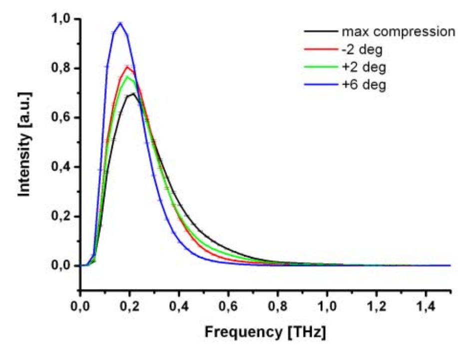
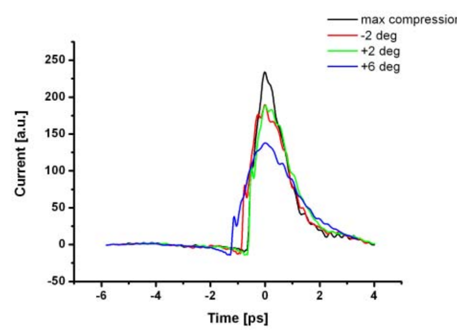


Figure 3: Comparison between interferograms with different accelerating phases.

the baseline as the blue curve shows. The corresponding corrected spectra (Fig.4a) show clearly the falling slope is steeper, the longer the bunch, because of the smaller high frequency content. Fig.4b shows the reconstructed bunch



(a) CDR measured spectra



(b) Electron bunch profiles

Figure 4: Characterization of the bunch shape for different values of ACC2-3 RF phase.

profiles with a steep rising slope and a long tail as expected from simulations. The bunch length (FWHM) plotted as function of the accelerating phase (Fig.5), shows a very good agreement with the results obtained from the phase scan curve (red squares in Fig.5): the maximum intensity corresponds to the shortest bunch. The width of the shortest peak is $1.2 \pm 0.1\ ps$.

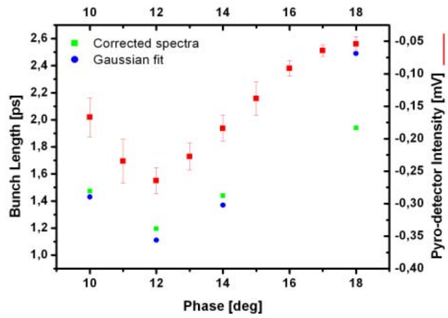


Figure 5: Comparison between the longitudinal bunch dimension and the intensity of the phase scan. Blue points correspond to the width of the difference interferogram, fitted with a Gaussian function, while green squares take into account corrections due to the finite size of the radiator, the Golay cell detector frequency response, the z-cut quartz window transmission and the interferometer acceptance.

Bunch Length and SASE Signal

Several measurements have been performed during SASE FEL operation to demonstrate the non-intercepting and non-invasive nature of CDR diagnostics.

The electron beam energy was $360\ MeV$, 8 bunches, $1\ nC$ per bunch, were transported. Fig.6 shows the history of the FEL intensity generating radiation at $32\ nm$.

Due to the very high beam current, wakefields generated on the DR screen could spoil the FEL process. However during the measurement no significant disturbance on the FEL radiation has been detected, confirming the effective non-perturbing nature of the technique. The measured

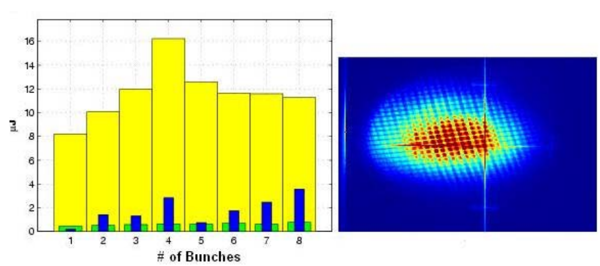
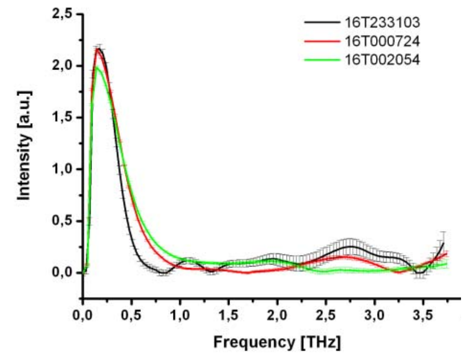


Figure 6: Energy history of the SASE operation and snapshot of the radiation spot.

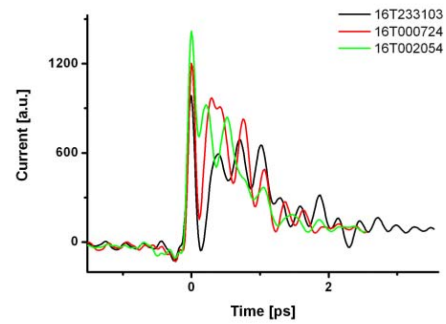
spectra and the corresponding profiles (Fig.7) show a noisy behavior due to the fact that the detector signal was noise-dominated.

CONCLUSIONS

The autocorrelation measurement of CDR has shown a clear dependence of the bunch length on the RF accelerating phase in agreement with the phase scan where the maximum intensity is detected at the phase of maximum compression. The analysis of the spectra, corrected by the low and high frequencies cut-off, allows a confident reconstruction of the bunch profile in good agreement with simulations and bunch length measurements done along FLASH with different techniques. Several measurements during FEL operation have shown how the insertion of a slit does not affect the FEL generation process, allowing the bunch profile measurement to be performed parasitically.



(a) CDR spectra



(b) Electron bunch profiles

Figure 7: Measurements during SASE operation.

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