

ELECTRON BUNCH MOMENTUM DISTRIBUTION MODULATIONS AT PITZ *

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Abstract

The Photo Injector Test facility at DESY, Zeuthen site, PITZ, develops and optimizes high brightness electron sources for Free Electron Lasers such as FLASH and the European XFEL. In last years shutdown period different components of the facility have been upgraded. One of the key upgrades was the installation of a new laser system that produces trains of flat top pulses with rise- and fall-times of less than 2 ps and a duration of 24 ps (FWHM). In this paper we report on the investigations of modulations in the electron bunch momentum spectra when modifying parameters of the laser system such as bandwidth or longitudinal pulse shape.

INTRODUCTION

During the last shutdown period of PITZ a new laser system, developed at MBI Berlin, has been installed. This laser system is capable of producing temporally flat top laser pulses by using an appropriate pulse shaper. Small misalignments of the pulse shaper lead in most cases to modulations on the flat top region of the laser pulses which influence the electron bunch properties, mainly the longitudinal phase space distribution.

After introducing the laser system and the experimental setup we present detailed investigations on the influence of the temporal laser pulse shape on the electron bunch momentum distribution and compare the results with simulations.

THE LASER SYSTEM

The laser system can produce temporally flat top pulses with a maximal duration of 24 ps (FWHM) and a wavelength of 257.5 nm arranged in trains of up to 800 pulses having a temporal spacing of 1 μ s. The train repetition rate is 10 Hz. The laser systems subcomponents are first a Yb:KGW oscillator producing infrared sub-picosecond pulses, having a repetition rate of 54 MHz. After reduction of the repetition rate to 1 MHz by use of a Pockels cell, the laser pulses are sent to a pulse shaper based on phase stabilized pulse stacking using birefringent crystals [1]. Afterward the laser pulses are amplified first in a regenerative amplifier and finally in a double pass and booster amplifier. These amplifiers use Yb:YAG as active medium whose

gain bandwidth is appropriate for amplifying pulses with 2 ps edges. Finally these pulses are converted to the UV and sent to the photo cathode.

For our investigations the temporal pulse shape has been modified on purpose. One way to do these modifications is the use of the pulse shaper. In its present form it consists of thirteen birefringent crystals used for stacking the pulses from the oscillator. After the pulse shaper fourteen, mutually delayed subpulses form the flat top distribution. By rotation of the crystals the intensity of each subpulse can be varied. For a detailed description see [1].

Another way of influencing the temporal shape of the laser pulse is the insertion of a Lyot filter into the regenerative amplifier. As described in [1] this filter reduces the spectral bandwidth of the laser pulses. This reduction results in a flattening of the plateau part of the temporal laser pulse shape and, as a byproduct, to an increase of the rise- and fall-times. The temporal laser shape is measured by means of an optical cross-correlation which has a resolution of better than 1 ps.

EXPERIMENTAL SETUP

The PITZ facility consist of a 1.6-cell L-band gun cavity operated in π -mode which provides electron beams with a momentum of up to 6.8 MeV/c. To further accelerate the beam a 9-cell L-band booster cavity is used. The final beam momentum is 14.8 MeV/c.

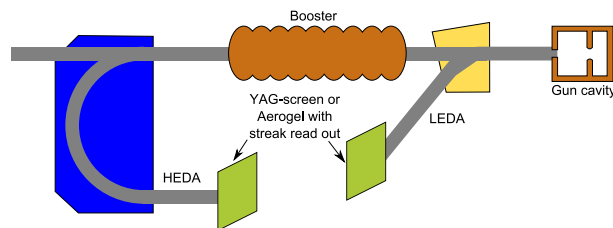


Figure 1: Schematics of the dispersive arms used in the measurement within the PITZ setup.

For the measurements of the momentum spectra and the longitudinal phase spaces two dispersive sections were used for this paper. One is located about 1 m downstream the gun, LEDA¹, which is designed to measure momenta of up to 8.8 MeV/c [2]. The second one, HEDA², is placed behind the booster cavity and is capable to measure momenta of up to 40 MeV/c [3]. Both dispersive sections

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¹LEDA = Low Energy Dispersive Arm

²HEDA = High Energy Dispersive Arm

allow to measure the longitudinal phase spaces by means of streak camera read out of Cherenkov light emitted by an Aerogel radiator. Fig. 1 shows a sketch of the beam line as it was described.

MEASUREMENTS

The experiments were divided into two different parts. The first part was dedicated to the characterization of the momentum modulations. In the second part the influence of the laser pulse parameters such as spectral bandwidth or flat top modulation depth on the momentum modulations have been investigated.

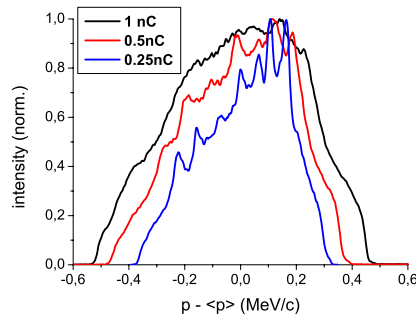


Figure 2: Momentum distributions for different bunch charges in HEDA. The no. of electron bunches used for this measurement was adjusted to achieve comparable signal strengths. No spectral filter was applied.

The momentum distributions were measured and characterized in LEDA as well as in HEDA for different combinations of gun and booster phases. In this paper we restrict to the presentation of measurements at gun and booster phases set to the maximum momentum gain + 10deg. This phase choice provides the best sensitivity for observing the modulations. More general these modulations are a property of the longitudinal phase space distributions. Since we were observing only the projection of the longitudinal phase space onto the momentum axis the detection of any modulation becomes difficult for small momentum spreads.

The electron beam mean momenta were 6.6 MeV/c for LEDA measurements and 14.5 MeV/c for HEDA measurements respectively. Fig. 2 shows measurements of the momentum distribution for different charges in HEDA. While the modulations are well pronounced for low charges, they are already smeared out by space charge effects at a charge of 1 nC. Therefore all subsequent measurements concentrate on a charge of 250 pC.

In the next experiment we investigate the influence of a possible change of the gradient and/or phase along the RF pulses in the gun and the booster on the measurement results. Therefore the momentum distributions were measured using different numbers of laser pulses in the train. Fig. 3 shows that there is only a small smearing effect. Even for 50 pulses the modulations can be clearly detected.

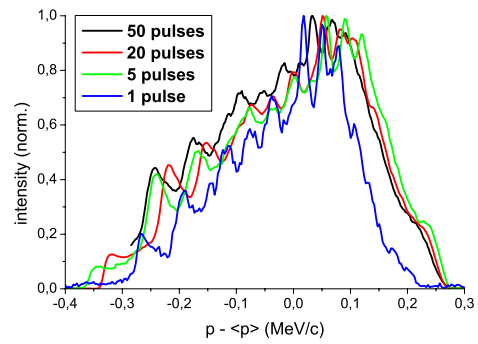


Figure 3: Momentum distributions for different number of pulses in HEDA. Charge is 250 pC. No spectral filter was applied.

In the next step different Lyot filters have been inserted into the resonator of the regenerative amplifier of the laser system. In Fig. 4(a)-(d) the resulting temporal laser shapes for three Lyot filters having different spectral transmission properties (broad, medium and narrow bandwidth filter) are depicted. In this stage of the experiment the pulse shaper settings have not been changed to keep the conditions constant. For the broad bandwidth filter almost no improvement of the temporal laser shape can be measured. The reduction of the spectral bandwidth appears to be negligible. The insertion of the medium and the narrow bandwidth filter lead to an improvement of the flatness of the plateau part and the expected increase of the rise- and fall-times

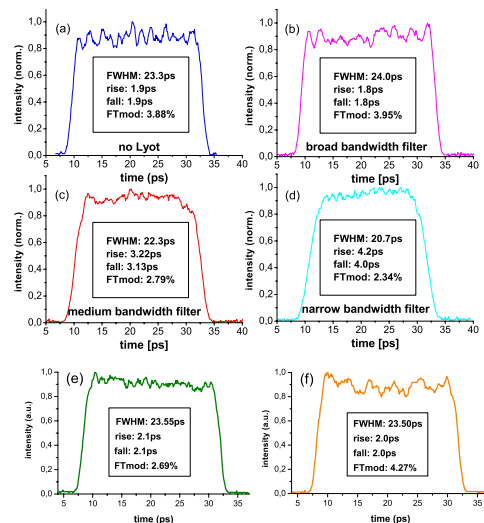


Figure 4: Different temporal laser pulse shapes used for the measurements. (FTmod means integrated modulation on flat top normalized to area under the curve).

(a)-(d) Temporal laser profiles obtained with different Lyot filters.

(e)-(f) Temporal laser profiles with medium Lyot filter. left side: optimized pulse shaper settings to get flat top, right side: intentionally detuned pulse shaper

is visible. In another experiment the pulse shaper has been used to intentionally introduce large modulations on the flat top part. In Fig. 4(e)-(f) the resulting temporal laser shapes are presented. For both cases the medium Lyot filter has been used. The profile on the left side was obtained by tuning the laser pulse shaper to give a good flat top with short rise- and fall-times, while on the right side the pulse shaper has been detuned. The numbers given in Fig. 4 are obtained by applying a non symmetric trapezoidal fit to the measured laser shapes.

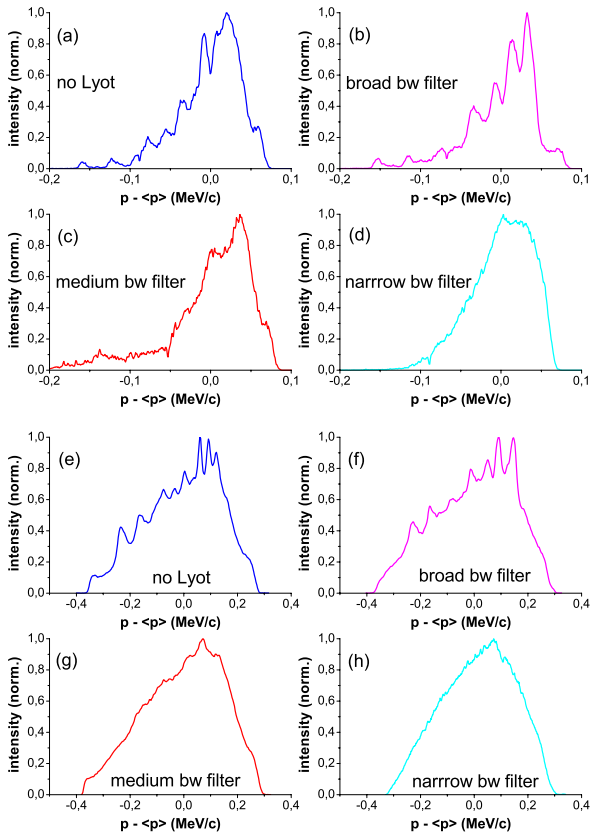


Figure 5: Momentum distributions for different Lyot filters (a)-(d) Measurement in LEDA using 30 bunches (e)-(h) Measurement in HEDA using 10 bunches

For the temporal laser profiles shown in Fig. 4(a)-(d) the momentum distributions have been measured in LEDA and in HEDA. In figure 5(a) and (b) one can clearly see the momentum modulations for the cases of no or broad bandwidth filter while the modulations are suppressed using a medium or narrow bandwidth filter.

Figure 6 shows the momentum measurements in HEDA for the case of a detuned pulse shaper. While the pulse having a smooth flat top only shows slight modulations in the momentum spectrum, the imperfections in the case of the detuned pulse shaper result in pronounced modulations.

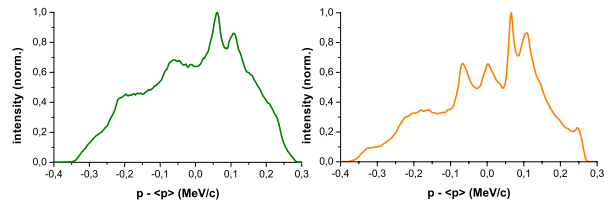


Figure 6: Momentum distributions for different pulse shaper settings.

The color code corresponds to Fig. 4(e)-(f)

THEORY AND SIMULATION

The accelerating field variation during photo emission in a RF gun is responsible for the conversion of modulations of the temporal laser profile to modulations in the longitudinal phase space distribution. In the case of the PITZ gun cavity operated a 1.3 GHz a laser pulse duration of 20 ps translates to 9.35 deg of RF phase. Taking into account the nominal launch phase of appr. 44 deg and a maximal electrical field of 60 MV/m at the head of the bunch is emitted at a gradient of 38.0 MV/m while the tail experiences a gradient of 45.1 MV/m. Therefore any structure on the temporal laser shape is not only converted to a bunch profile modulation, as it is the case for DC guns, but also to a modulation in the momentum distribution.

Table 1: Parameters for the Simulations

gun gradient	64 MV/m
gun phase	+10 deg off-crest
booster gradient	14 MV/m
booster phase	+10 deg off-crest
charge	250 pC
laser spot size	circular flat top
.	1.36mm diameter

To further understand the results of the measurements various simulations have been performed using the ASTRA code [4]. The machine settings used for the simulations are summarized in table 1. The temporal laser shape has been varied. Starting from a 20 ps FWHM flat top laser pulse shape with rise- and fall-times of 2 ps, ten sinusoidal modulations with various depths have been added to the flat top part. The electron bunches have been tracked until the end of the booster cavity.

In figure 7(a) and (b) an overview of the temporal laser shapes that were used for the simulations and the corresponding simulated momentum distributions downstream the booster are shown. The very sharp spikes present in the momentum distributions will be smeared out in the experiment due to the limited resolution of the momentum measurements systems, which is 3 keV/c for LEDA and appr. 8 keV/c for HEDA not including CSR effects. But the fact that even small imperfections of the flat top part

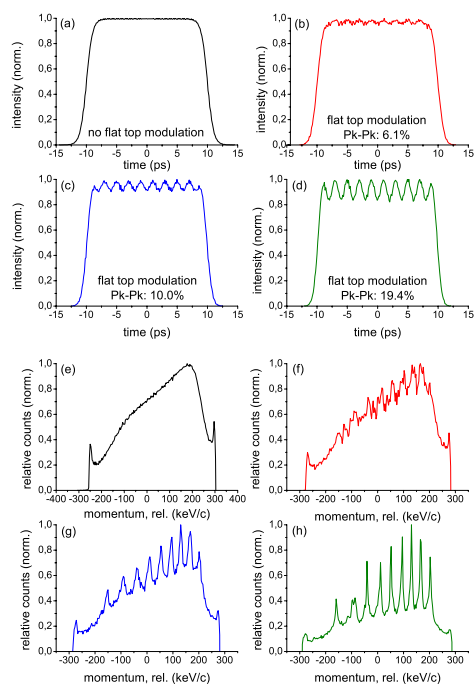


Figure 7: Input parameters and simulation results
 (a)-(d) Temporal laser shapes used for the simulations
 (e)-(h) Simulated momentum distributions downstream the booster cavity

of the laser pulse temporal shape can cause significant modulations in the momentum distribution of the electron bunches agrees well between experiment and simulation.

It should be mentioned that the modulations on the flat top part of the laser pulses as shown in Fig. 4(a)-(f) should have only a minor influence on the transverse emittance. From simulations we know that for example a laser pulse having five sinusoidal modulations of depth 40% (Pk-Pk) the increase of the transverse emittance is only 5.2%.

SUMMARY AND CONCLUSIONS

Small misalignments of the laser pulse shaper can lead to modulations on the flat top part of the temporal laser pulse shape. In this paper we reported on investigations on changes of the electron bunch momentum distribution depending on the temporal profile of the laser pulses. It has been shown that laser pulse flat top modulations introduced by an intentional pulse shaper detuning resulted in modulations of the longitudinal momentum of the electron bunches. These modulations could be observed after the gun as well as after the booster cavity. They have been detected for electron bunch trains and for single electron bunches. The modulations in the momentum distributions were found to be smeared out for a charge of 1 nC due to space charge effects. Finally it was shown in Fig. 4(e) that even for the medium Lyot filter the specification of rise- and fall-times as short as 2.5 ps for 0-100% (or 2 ps for 10-

90%) can be fulfilled. Therefore the medium Lyot filter can be used to efficiently suppress the momentum modulations in the low charge regime.

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