FIRST MEASUREMENTS OF THE LONGITUDINAL PHASE SPACE DISTRIBUTION USING THE NEW HIGH ENERGY DISPERSIVE SECTION 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 (FELs) like FLASH and the European XFEL. A new multi-purpose dispersive section was designed [1, 2] and installed to characterize the momentum distribution, the longitudinal phase space distribution and the transverse slice emittance of the electron bunch for an electron energy up to 40 MeV. The spectrometer consists of a 180 degree dipole magnet followed by a slit, a quadrupole magnet and two screen stations. One of the screen stations allows the measurement of the longitudinal phase space distribution. The first measurement results and corresponding beam dynamics simulations of the momentum and the longitudinal phase space distributions will be reported in this contribution. The resolution of the system will be analysed and compared to the design expectations.

INTRODUCTION

The main goal of PITZ is to test and to optimize L-Band RF photo injectors for Free-Electron Lasers (FELs) like FLASH and XFEL at DESY in Hamburg and to study the emittance conservation by using a matched booster cavity. The demands on such a photo injector are a small transverse emittance, a charge of about 1 nC and short bunches (of about 20 ps). Besides the accelerating (gun and booster) cavities, the electron beam line of PITZ consists mainly of diagnostics elements. In 2008 a new multi-purpose dispersive section was installed downstream the booster cavity to characterize the momentum distribution, the longitudinal phase space distribution and the transverse slice emittance [3] of the electron bunch for an energy up to 40 MeV.

THE SETUP

Figure 1 shows the layout of the new installed first high-energetic dispersive arm (HEDA1). It consists of a 180 degree dipole spectrometer (deflecting in vertical direction) followed by an insertable slit, a quadrupole magnet (DISP2.Q1) and two screen stations (DISP2.Scr1&2). The first screen stations (DISP2.Scr1) is equipped with a YAG-screen imaged onto a 8-bit TV-camera[1] for momentum measurements and a Cherenkov radiator (Silica aerogel, thickness of 5 mm and a refractive index of n = 1.05) [4] to measure the longitudinal phase space distribution using an extended optical read-out and a streak camera [5]. All the results presented in this paper have been made using DISP2.Scr1. DISP2.Scr2 is currently mainly used for transverse slice emittance measurements [3] which are not presented in this paper.

The position where a particle hits the screen after passing the dipole magnet depends on the momentum, the transverse position and the angle of the particle before it enters the dipole spectrometer, according to the first order transport matrix:

$$y_{DA} = R_{11} y_0 + R_{12} y_0' + R_{16} \frac{\Delta p_0}{p_0}, \quad (1)$$

where y_0, y_0' and $\frac{\Delta p_0}{p_0}$ are the position, divergence and relative momentum deviation of the particle at the entrance of the dipole magnet and R_{11}, R_{12} and R_{16} are the dipole matrix elements. For a 180 degree dipole spectrometer without pole face rotation these values become:

$$R_{11} = -1, \quad R_{12} = -L_{DA}, \quad R_{16} = 2r, \quad (2)$$

with L_{DA} the drift length between the dipole exit and the screen station where the measurement is performed and r the deflecting radius.

When the dipole magnet is switched off the vertical position of a particle at longitudinal position L_{drift} downstream the dipole entrance is given by:

$$y = 1 y_0 + L_{drift} y_0'. \quad (3)$$

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[1] In the future this 8-bit camera will be replaced by a 12 bit camera with a higher sensitivity

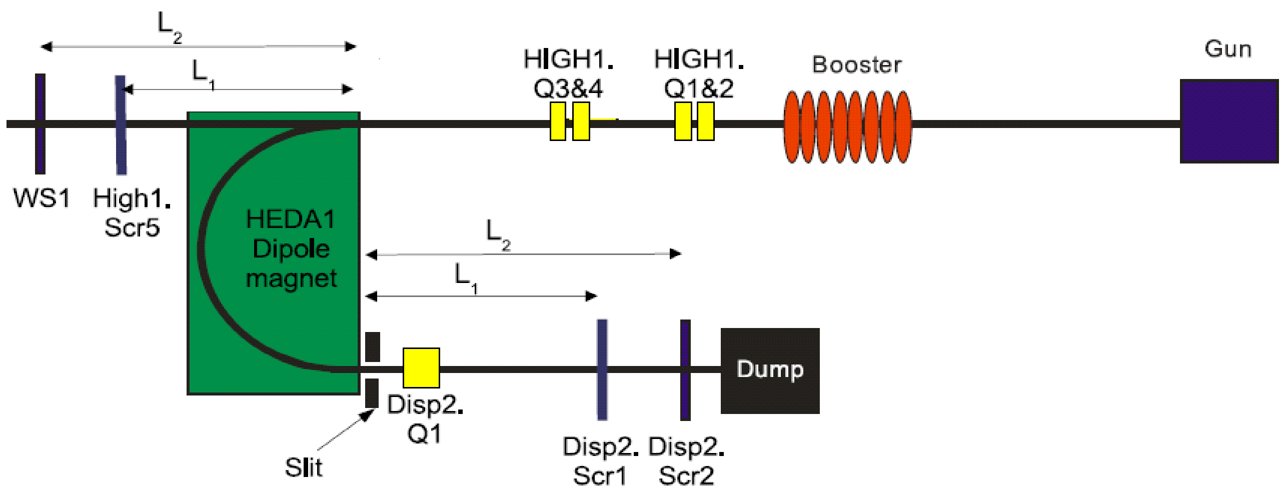

Figure 1: Schematics of the design of the first high-energetic dispersive arm (HEDA1).

This means, when the vertical beam size is minimized at a screen located $L_{drift} = L_{DA}$ (labeled L_1 in figure 1) downstream the dipole entrance also the influence of the initial beam size and divergence to the momentum spread measurement is minimized.

In front of the dipole magnet two quadrupole-doublets are situated, mainly the quadrupole-doublet HIGH1.Q1&2 is used to focus the beam to reach a high resolved momentum measurement.

MEASUREMENTS OF THE MOMENTUM DISTRIBUTION

Figure 2 shows a measured momentum distribution compared to simulations for a main solenoid current of 390 A, a maximum accelerating field of 60 MV/m at the photo cathode, a charge of 250 pC, a gun phase of maximum momentum gain + 10° and a booster phase of maximum momentum gain + 10°. The beam was focused on the reference screen (HIGH1.Scr5) in vertical direction, in order to minimize the influence of the beam size and divergence to the resolution. Both distribution show a good agreement, nevertheless some difference are visible in the distributions. These differences are caused by the residual influence of beam size and divergence as well as inaccuracies in the entrance parameters of the ASTRA simulation (e.g. of the cathode laser distribution).

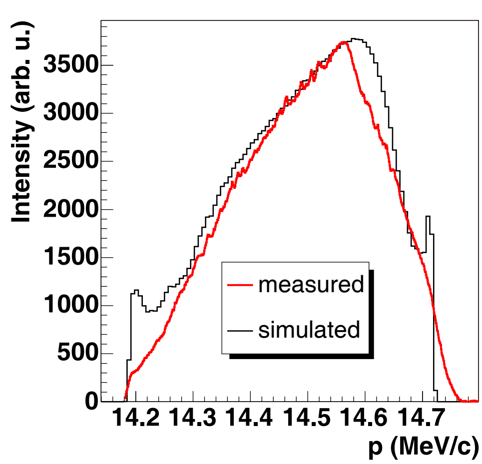

Figure 2: Comparison of measured and simulated momentum distribution for a charge of 250 pC, a gradient of 60 MV/m at the cathode, gun phase of maximum momentum gain + 10° and booster phase of maximum momentum gain +10°.

MEASUREMENTS OF THE LONGITUDINAL PHASE SPACE DISTRIBUTION

Figure 3 shows the measured longitudinal phase space distribution for a maximum accelerating field of 60 MV/m at the photo cathode, a gun phase of maximum momentum gain and a booster phase of maximum momentum gain - 10°. In figure 4 the corresponding simulated longitudinal phase space distribution is shown.

The shape of the measured longitudinal phase space distribution for gun and booster phase of maximum momentum gain is comparable to the simulated one, but the area of the phase space distribution and thus the longitudinal emittance and the slice momentum spread is still larger in the measurement than in the simulation. This limitation is mainly caused by the resolution of the streak camera of 2 ps (Hamamatsu C5680) and the optical transmission line. Therefore the simulated longitudinal phase space distribution was convoluted with the response function of the streak camera (shown in figure 5) to estimate the limitation of the resolution of the measurement by the streak camera. This distribution including the streak camera resolution smears out the details in the simulated longitudinal phase space distribution and small modulations are not recognizable anymore. It is much closer to the measure-

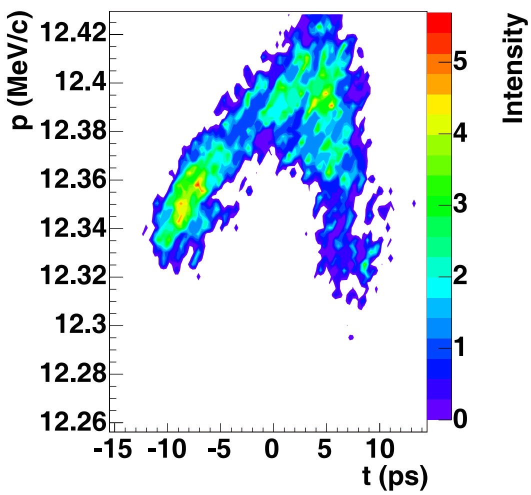

Figure 3: Measured longitudinal phase space distribution for a gradient of 60 MV/m at the cathode, gun phase of maximum momentum gain and booster phase of maximum momentum gain $-10°$.

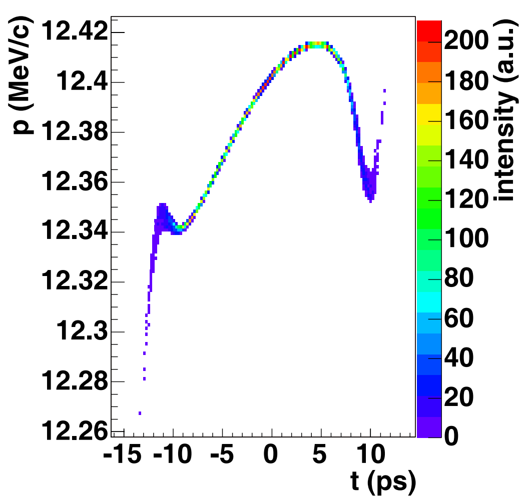

Figure 4: Simulated longitudinal phase space distribution for a gradient of 60 MV/m at the cathode, gun phase of maximum momentum gain and booster phase of maximum momentum gain $-10°$.

ment, even there are still discrepancies between measurement and simulation. The low intensive head of the bunch seen in the simulation is not visible in the measurement, most probably this is a problem of sensitivity. One also has to take into account that the measurement is an average of 100 bunches and a small phase or gradient jitter of the accelerating cavities is impacting the bunch momentum and blurs the longitudinal phase space with its narrow slice momentum spread.

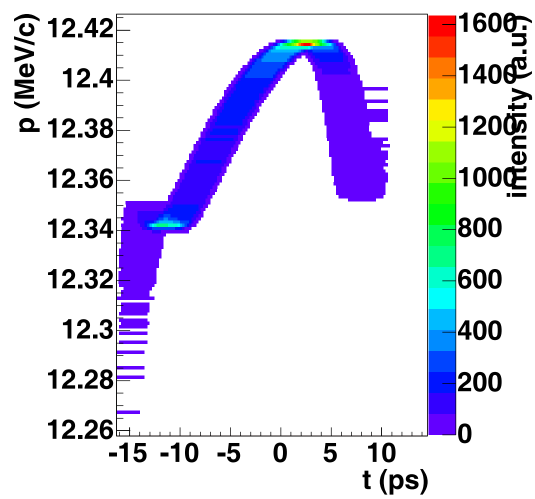

Figure 5: Simulated longitudinal phase space distribution for a gradient of 60 MV/m at the cathode, gun phase of maximum momentum gain and booster phase of maximum momentum gain $-10°$ convoluted with the resolution of the streak camera.

SUMMARY

The measurement of the momentum distribution and longitudinal phase space distribution using the new multipurpose dispersive section (HEDA1) has been presented. A reproduction of the measured momentum distribution by simulations has been shown. Also the measured longitudinal phase space distribution could be reproduced by ASTRA simulations taking into account the resolution of the streak camera used for the measurement.

ACKNOWLEDGMENT

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