FIRST MEASUREMENT RESULTS FROM THE UPGRADED LOW ENERGY LONGITUDINAL PHASE SPACE DIAGNOSTICS AT PITZ *

J. Rönsch†, J. Rossbach, Hamburg University, 22761 Hamburg, Germany
D. Richter, BESSY, 12487 Berlin, Germany
S. Lederer, D. Lipka, DESY, Hamburg, Germany
G. Asova‡, J.Bähr, C. Boulware, H. J. Grabosch, L. Hakobyan§, M. Hänel, Y. Ivanisenko
M. Khojoyan, M. Krasilnikov, B. Petrosyan, S. Rimjaem, A. Shapovalov¶, T.Scholz, L. Staykov‖,
R. Spesyvtsev, F. Stephan, DESY, 15738 Zeuthen, Germany
K. Rosbach, Humboldt University Berlin, 12489 Berlin, Germany

Abstract

The Photo Injector Test facility at DESY, Zeuthen site (PITZ) was built to optimize electron sources and to study electron beam characteristics for short wavelength Free-Electron Lasers (FELs). In addition, using a further accelerating ('booster') RF cavity, the so-called emittance compensation mechanism is under investigation at PITZ. Due to the upgrade of the PITZ facility the gap width of the dipole spectrometer downstream the RF gun cavity was too small and had to be modified. A slit was added in front of the spectrometer to improve the momentum resolution. Design considerations are discussed and first measurement results are presented. Furthermore, the bunch length measurements downstream the gun has been adapted to higher energies.

INTRODUCTION

The main goals of PITZ are to test and to optimize L-Band RF photo injectors for Free-Electron Lasers. The requirements on such a photo injector are small transverse emittances, charge of about 1 nC, short bunches (with a length of about 20 ps FWHM) and the possibility of long bunch trains. The heart of PITZ is a 1.5 cell copper gun cavity surrounded by a solenoid magnet that is used to focus the beam. Starting from the end of 2007 a new gun cavity has been conditioned. First measurements of the longitudinal properties accelerated by this gun are analysed. For all the measurements presented in this paper a short (2,ps FWHM) Gaussian pulse has been used. The electron beam diagnostics at PITZ has also been improved during the most recent shutdown period. For the diagnostics of the longitudinal phase space the low energetic spectrometer and the bunch length measurement system downstream the gun cavity were modified, and the 180°-dipole [1] spectrometer arm in the high energy section (downstream the booster cavity) was added. The low energetic dispersive arm (LEDA) is situated about 1.1 m downstream the cathode. A problem of the initial low energy dipole spectrometer, in operation at PITZ, was the small distance of the pole shoes of only 20 mm, which corresponds to an inner size of the vacuum chamber of 12 mm. For certain solenoid currents the beam size at the position of the dipole magnet exceeds the vacuum chamber. This is the case especially for those settings were the smallest transverse emittance is expected, at locations significantly downstream the booster cavity. Figure 1 shows the total beam size as a function of

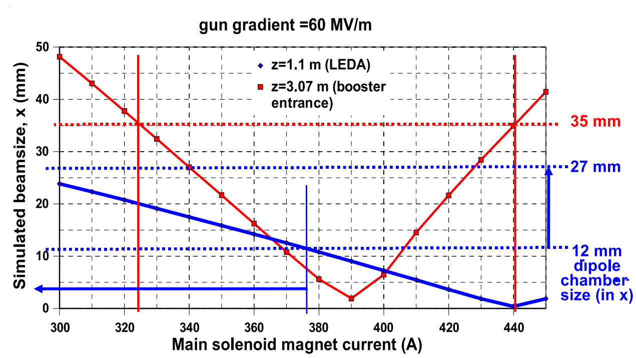


Figure 1: Simulated beamsize at the booster entrance and inside the LEDA dipole magnet for different solenoid currents. Simulations were done for 60 MV/m and phase of maximum momentum gain. Limitations due to the vacuum chamber at the booster entrance and within the LEDA dipole are shown.

the main solenoid current at the entrance of the booster and at the center of the LEDA dipole. The beam tube at the entrance of the booster cavity having a aperture diameter of 35 mm defines the usable range of solenoid currents (325 A - 440 A). This was further limited for the smaller solenoid current due to the dipole chamber width (377 A-440 A).

* This work has partly been supported by the European Community, contract numbers RII3-CT-2004-506008 and 011935, and by the 'Impuls- und Vernetzungsfonds' of the Helmholtz Association, contract number VH-FZ-005.

† jroensch@ifh.de
‡ On leave from INRNE, Sofia, Bulgaria
§ On leave from YerPhI, Yerevan, Armenia
¶ On leave from MEPHI, Moscow, Russia
‖ On leave from INRNE, Sofia, Bulgaria

DIPOLE DESIGN CONSIDERATIONS

An increase of the inner chamber size to at least 20 mm is required to avoid limitations of the solenoid current by the dipole. Since a misalignment in the beamline or a displacement from the design orbit has to be assumed a chamber size wider than 20 mm is preferable. A dipole gap width of 35 mm has been chosen as a compromise between the required magnetic field, the influence of fringe fields and space requirements within the beam tube. This gap width corresponds to an inner chamber size of 27 mm. Since the pole shoes of this magnet are small compared to the gap width, fringe fields have a significant influence on the field distribution and have to be taken into account. This means the matrix formalism does not give a sufficient accuracy for the re-design. Therefore the magnetic fields for different entrance and exit pole face rotation and deflection radii were simulated[1] and typical electron bunches with different solenoid focussing were traced through the simulated field. The position of the screen station in the dispersive section was kept fix for mechanical reasons. For high resolution of the momentum and longitudinal phase space measurement a slit of 0.1 mm was added to the beamline, upstream the dipole entrance. However, the optimization of the dipole parameters was done for measurements without using the slit. The deflection radius was increased as much as spatial restrictions allow. Figure 2 shows the relative error of the simulated momentum spread measurement as a function of the exit pole face rotation (β_{out}) for different focusssing of the gun solenoid. An entrance pole face rotation $\beta_{in} = 0°$, a deflection radius $r = 150$ mm and an electron beam with a momentum of 6.6 MeV/c have been used. Figure 2 shows that for solenoid currents below 460 A ($B_{peak} = 268$ mT) the resolution of the measurement gets worse. Also a change of the entrance pole face rotation does not improve the situation. A pole shoe with $\beta_{in} = 0°$, $\beta_{out} = -25°$ and $r = 150$ mm was chosen.

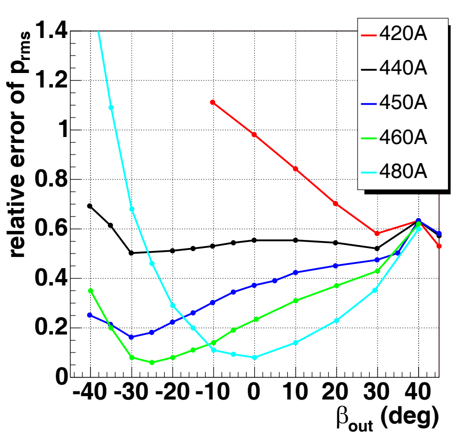


Figure 2: Relative error of the simulated momentum spread measurement as a function of the exit pole face rotation (β_{out}) for different solenoid focussing, a dipole spectrometer with an entrance pole face rotation $\beta_{in} = 0°$ and a deflection radius $r = 150$ mm.

[1]using CST (*C*omputer *S*imulation *T*echnology), a software package for electromagnetic field simulations.

MOMENTUM MEASUREMENTS

Figure 3 shows the measurements and the simulations

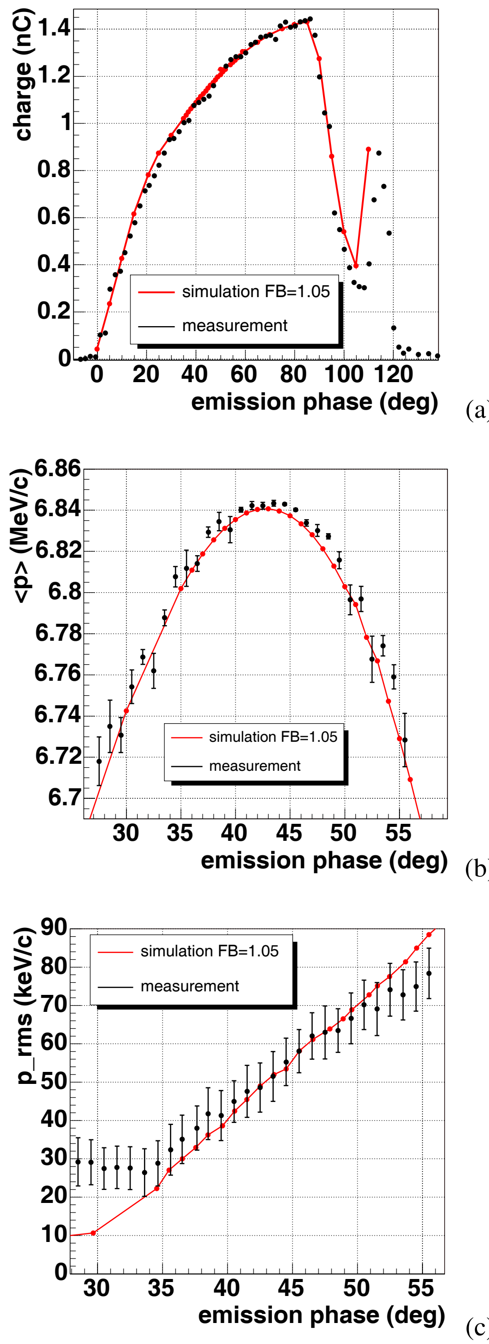


Figure 3: Measured and simulated charge (a), mean momentum (b) and momentum spread (c) as a function of the gun phase. The measurement was done using a solenoid field of around 277 mT, a transverse flat top laser distribution with 2 mm diameter and longitudinal a Gaussian pulse with a duration of 2 ps FWHM.

of charge (a), mean momentum (b) and momentum spread (c) as a function of phase difference between laser and RF. For the simulation a gradient of 60 MV/m at the cathode and a Gaussian longitudinal cathode laser distribution with a duration of 2 ps FWHM have been used. The measurement of the momentum distribution has been performed a a smaller phase range than the charge, without the usage of the slit upstream the dipole. The error bars of the momentum spread measurement result from statistical and systematic errors. The systematic errors of the momentum spread measurement arise mainly from the initial transverse beam size and the divergence of the bunch. For the mean momentum measurement systematic errors which apply to all phases used in this momentum measurement, like the uncertainty of the deflection angle and the alignment have not been taken into account. Because the gradient of 60 MV/m used in the simulation was not obtained from measurements, but fitted to match to the momentum measurement.

A measurement using the modified spectrometer dipole magnet with the slit of 100 μm width in front of the dipole is shown in figure 4 compared to ASTRA a simulation. The slit was used during the measurement to improve the resolution. To reach a sufficient signal to noise ratio 50 pulses have been overlapped. The measurement was performed

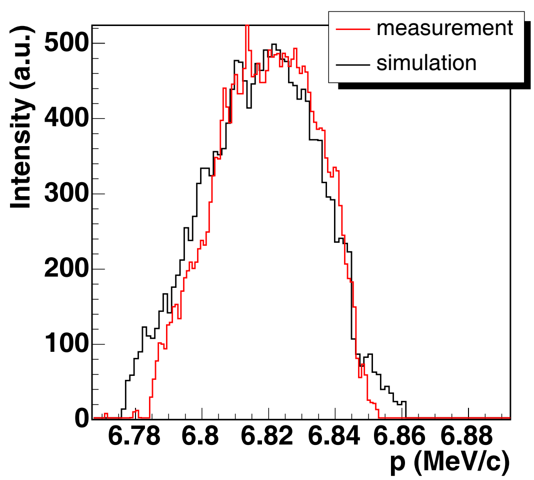


Figure 4: Measured momentum distribution of the gun using the re-designed dipole spectrometer compared to ASTRA simulations of the beam.

for a Gaussian longitudinal laser distribution with a FWHM of 2 ps, a gradient of 60 MV/m at the cathode, the phase of maximum momentum gain, an rms transverse laser beam size of 0.58 mm and a peak solenoid field of about 270 mT. The simulated momentum distribution at the position of the slit could be reproduced with a good agreement. The high and the low energetic part of the bunch are underestimated in the measurement. Since the focussing on the slit and thus the number of particles passing the slit are energy dependent.

Figure 5 shows the simulated and measured mean momentum for the phase of maximum momentum gain for

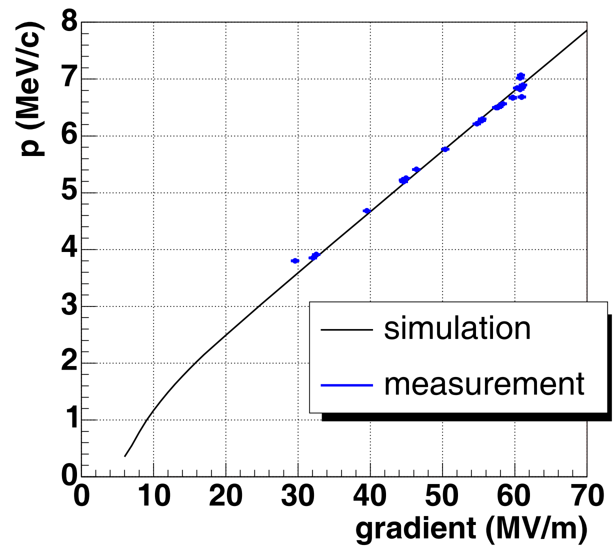
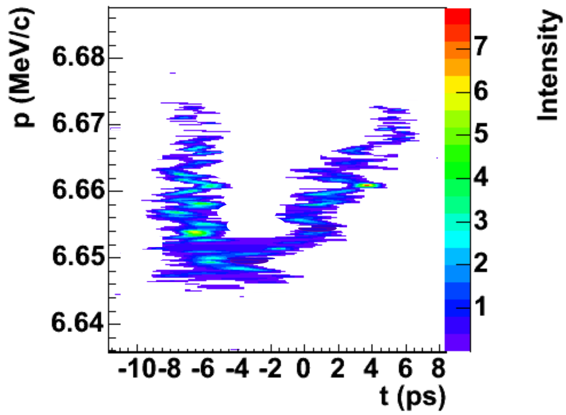


Figure 5: Simulated and measured maximum mean momentum as a function of the maximum field at the cathode.

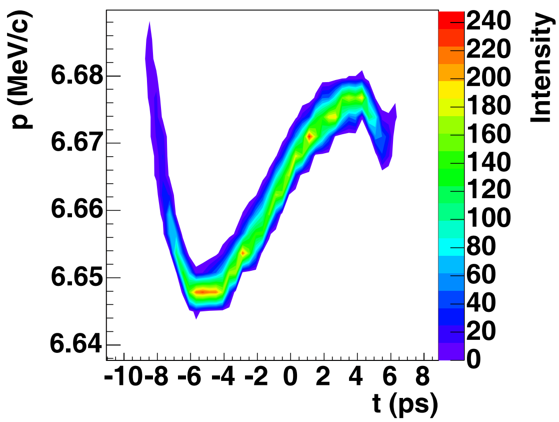
different gradients. In the measurement the RF power (P) in the gun was determined instead of the gradient. The accelerating gradient at the cathode (E) was calculated by: $E = K\sqrt{P}$. K was determined in comparison with the simulation by the least square method with $K = 2.25 \cdot 10^4 \frac{V}{m\sqrt{W}}$. Statistical errors of the momentum and the power measurement are included in the graph, but the error bars are too small to be visible. The measurements have be taken on different days, at a gradient of about 61 MV/m. The results differ by about 0.3 MeV/c. A possible reason for this discrepancy is that the gun was not fully conditioned during the measurement and the quality of the cavity improved during the operation. The measurement will be repeated after finishing the conditioning of the gun. It also has to be taken into account that especially at the limit of the klystron (at high power) subharmonics can occur which influence the RF power measurement.

LONGITUDINAL PHASE SPACE MEASUREMENTS

First longitudinal phase space measurements using the modified gun spectrometer dipole magnet and the slit upstream the spectrometer have been performed. Figure 6 shows an example of the first measurement results compared to a simulation. This measurement was performed for a longitudinal Gaussian laser pulse with a duration of 2 ps FWHM, and a flat-top transverse laser distribution with a diameter of 2 mm. The phase of this example is optimum phase - 7°. For this phase, the longitudinal phase space is strongly non-linear and thus the resolution of the system can be estimated. Although the bunch length is 12.7 ps (FWHM) and the rms momentum spread is only 10.4 keV/c, the shape of the longitudinal phase space could be reconstructed. The measurement and the simula-



(a)



(b)

Figure 6: Measured (a) and simulated (b) longitudinal phase space for a Gaussian laser pulse with a duration of 2 ps FWHM.

tion show some similarity, but the signal-to-noise ratio of the measurement is weak, therefore modulations appear by correcting the influence of the streak camera to the resolution. The resolution of the streak camera (Hamamatsu, C5680) of 2 ps.

BUNCH LENGTH MEASUREMENTS

The operation at energies larger than 6 MeV/c required a modification of the Cherenkov radiator in the system used for bunch length measurements downstream the gun [2]. Because the increased emission angle could not be collected by the aperture of the optical system. Therefore the index of refraction of the Cherenkov radiator has been reduced from $n = 1.03$ to 1.008.

According to the longitudinal laser distribution the transverse distribution has to be optimized in order to reach an electron beam with small transverse distribution. Its influence to the longitudinal parameters is shown here. Figure 7 shows the measured and simulated bunch length for a Gaussian longitudinal laser distribution with a duration of

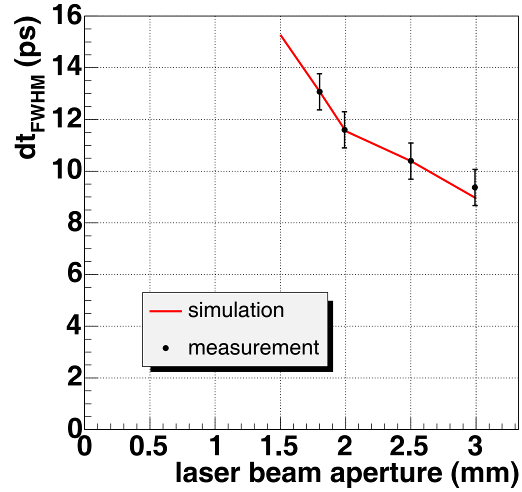


Figure 7: Influence of the transverse laser beam size on the bunch length for a Gaussian laser pulse of 2 ps FWHM, a peak field of the main solenoid 210 mT and a bunch charge 1 nC.

2 ps FWHM, a peak field of the main solenoid 210 mT and a bunch charge 1 nC. Measured and simulated bunch length increase with decreasing transverse laser beam size, due to the increase of the charge density and thus the space charge forces. This increase in the bunch length with decreasing transverse laser beam size results in a decrease of the peak current and reduces thus the transverse space-charge forces. This emphasizes the correlation of the transverse and longitudinal properties of the bunch in the space charge dominated energy regime.

SUMMARY

The dipole spectrometer downstream the gun cavity was modified. Design considerations and first measurement results of momentum and longitudinal phase space are presented. The modified screen station for the measurement of bunch length downstream the gun was taken into operation successfully. The measurement results achieved with the modified system were discussed in the paper.

REFERENCES

[1] S. Khodyachykh et al., "Design and Construction of the Multipurpose Dispersive Section at PITZ", Proceedings of DIPAC 2007, Venice, Mestre, Italy 2007

[2] D. Lipka, "Investigations about the longitudinal phase space at a photo injector for minimized emittance", PhD Thesis 2004 Humboldt University Berlin