Phase Scan Measurements and Simulations at PITZ

Alexander Wolf
Humboldt-Universität zu Berlin
Newtonstraße 15, 12489 Berlin, Germany
Email: alexander.m.wolf@gmx.net

Different measurements were performed at the RF Photo Injector Test Facility at DESY Zeuthen in order to investigate the influence of the focussing magnetic field (B) on RF phase scans. The total charge of the outcoming beam depends on the time of electron production and the time dependent amplitude of the accelerating electrical field in the cavity. The relevant laser parameters for the simulation were optimized for a magnetic field B=0. Phase scans were simulated for varying field strengths and two different transversal laser profiles. A good agreement was found between experiment and simulations. However, both profiles lead to a systematically higher emittance than expected although the deviation is in general less for a radial distribution of the transversal laser profile than for a symmetrical gaussian profile.

1 Introduction

1.1 What is PITZ?

The acronym PITZ stands for **P**hoto **I**njector **T**est Facility at DESY **Z**euthen. PITZ is part of the preparation programme for TESLA as well as the **X**-ray **F**ree-**E**lectron-**L**aser. Such accelerators, unlike synchrotrons, need excellent beam conditions right from the beginning, since there are no mechanisms to improve beam quality during the run. In order to satisfy the needs, an electron source that extends to the technical limits, is requested.

It was agreed to build PITZ, to overcome existing problems on the RF gun and to find optimum settings for the **T**esla **T**est **F**acility, because "experience shows that without an experimental program no significant progress can be expected"[**?**].

1.2 Generation of the electron beam

The RF photo injector test facility was installed at DESY Zeuthen under the objective to produce a stable electron beam with a repetition rate of 10 Hz. The bunches should have a nominal charge of 1 nC ($\approx 10^{10}$ electrons per bunch) with less than 1% energy spread and a small transverse projected emittance of about 1π mm mrad.

Conventionally, electrons are produced and accelerated by heating up a filament in an electrical field. This is a plainly statistical process, hardly capable of fulfilling the needs of modern accelerators such as TESLA or the X-FEL.

The RF photo injector uses the combined production and acceleration: A laser-pulse hits a caesium-telluride-cathode from which via photoeffect a, in space and time well defined bunch is emitted. To prevent the bunch from diverging dramatically due to high coulomb forces, the electrons have to be accelerated at once. Therefore the cathode is situated right inside a 1.5 cell copper cavity. The accelerating field in the resonator is a function of z and varies in time as shown in Eq. (**??**).

$$E(z,t) = E_0(z) sin(\omega t + \phi). \qquad (1)$$

Assuming a laser pulse hits the cathode at $t_0 = 0$, the phase difference between the RF-field and the laser input is ϕ. The electrons only leave the cavity for a narrow range of phases, otherwise they are accelerated backwards onto the cathode or oscillate inside the resonator. For an optimum phase the electrons reach almost speed of light, because the electron mass of 0.5 MeV is negligable in comparison to an energy gain of about 40 MeV/m. With increasing momentum the transversal Lorentz forces decrease, and the electrons move along the beampipe within a compact bunch.

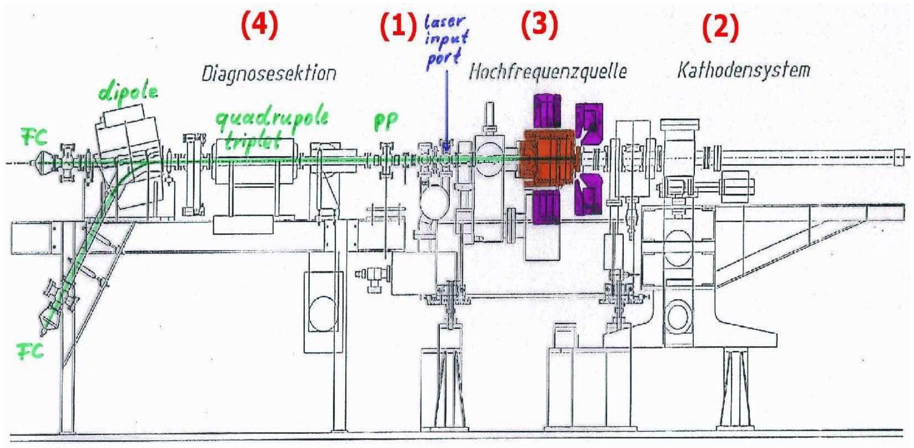

Fig. 1: *PITZ setup[?]: (1) Laser input port; (2) Cathode system; (3) RF source and solenoid magnets; (4) Diagnostic section; PP - pepper pot; FC - Faraday cup*

1.3 Diagnostics and beam tracking

PITZ consists of different parts. The laser is produced externally and guided via an adjustable mirror system into the beam pipe onto the cathode ((2) Fig. (**??**)). The Cs-Te-cathode is very sensitive to pollution, so a good vacuum ($\approx 10^{-9}$mbar) has to be provided. Radio waves with a power of 5 MW and a frequency of 1.3 GHz are produced externally by a klystron system and coupled into the cavity by waveguides ((3)Fig. (**??**)). Since a part of the power is converted into heat, the cavity has to be constantly cooled by a water cooling system, in order to prevent thermal deformations, which would result in the resonator going out of tune.

Two solenoid magnets for beam focusing surround the resonator. The main magnet is mounted on micromovers, because an exact positioning of the solenoids is crucial for a stable beam.

The first diagnostic part consists of a pepper pot (PP) for transverse emittance measurement and a Faraday cup to determine the charge. In the diagnostic section ((4)Fig. (**??**)) the beam is focussed by a quadrupole triplet. The field of the dipole magnet allows to measure beam energy and energy width.

For further details see [**?**].

2 Phase Scans

The experiment was performed at a klystron voltage, corresponding to an energy gain of about 41.8 MeV/m at the cathode. The laser intensity was adjusted as such, that 1nC is detected at the Faraday cup for ϕ_0, the phase of maximum energy gain. The charge was measured by a scanning programme, for phases from -180 deg to +180 deg in steps of two degrees, for solenoid currents ranging from 0 A to 400 A in steps of 20 A (Fig. (**??**)). To estimate the statistical fluctuations, the charge was measured for each point 2-3 times.

For further processing, the data was shifted and mirrored, $\phi \rightarrow \phi_0 - \phi$, to be comparable with the simulations.

3 ASTRA Simulation

ASTRA[1], **A S**pace charge **Tr**acking **A**lgorithm, allows to simulate the evolution of a charged bunch under the influence of external electromagnetic fields (cavity, solenoid, dipol, quadrupol ...) and internal space-charge-forces [**?**]. Since it is not possible to calculate the trajectory of every single electron in finite time, the charge Q is subdivided into N equally charged macro-particles. Experience has shown that for N=10000 ASTRA produces results of adequate accuracy. [2]

In order to simulate the influence of the solenoid, ASTRA takes the magnetic field strength B as a parameter. The correspondence between the current I, measured in the experiment, and B can be expressed by an empirical equation (**??**).

[1] http://www.desy.de/~mpyflo

[2] For a qualitative picture, as needed for preliminary simulations, N=2000 is sufficient.

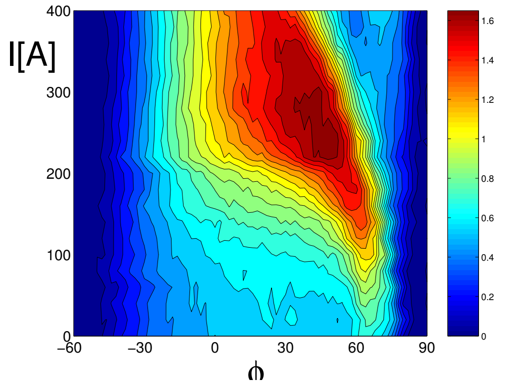

Fig. 2: *The experimental results are plotted for the phase ϕ over the solenoid current. The colors describe the measured charges, ranging from 0 nC to 1.65 nC.*

$$B[mT] \approx 0.6I[A] - 0.4 \tag{2}$$

To find experimentally less accessible parameters such as the longitudinal and transversal laser profile, different settings were simulated for B=0 and compared to the experimental curve I=0.

Shifting the data to the phase of maximal energy (Fig. (**??**)), $\phi^{sim} \rightarrow \phi^{sim} - \phi_0^{sim}$, as it was done for the experimental curves, the deviation Δ can be calculated (Eq. (**??**)).

$$\Delta = \sum w_j (C_j^{sim} - C_j^{exp})^2 \tag{3}$$

The weights w_j are functions of the experimental errors with $\sum w_j = 1$.

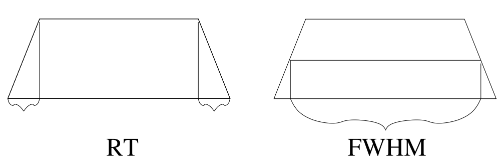

Fig. 3: *Characteristics of the flat top laser profile*

In the first run, the transversal laser profile is assumed to be symmetrically gaussian with an optimum value of rms size $\sigma_{x,y} = (0.4 \pm 0.05)mm$. The longitudinal profile has a flat-top shape, characterized by its rising time and its full width at half maximum (FWHM) as it is outlined in Fig. (**??**). Best agreement was found for RT = (3±0.5) ps and FWHM = (25±0.5) ps. An initial charge of 1.6 nC gave a good correspondence.

Fig. (**??**) shows the simulation for the gaussian profile. Although the simulated curve for

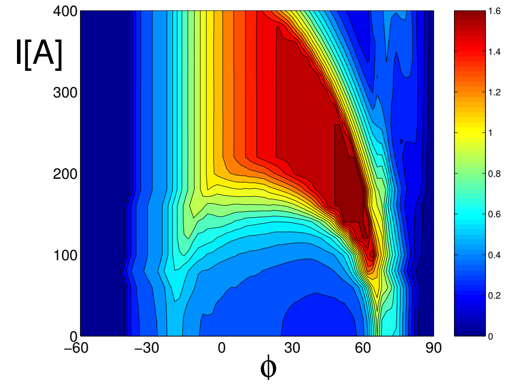

Fig. 4: *Gaussion profile: The simulated charge is plotted for the phase ϕ over the solenoid current. The colors describe the measured charges, ranging from 0 nC to 1.6 nC.*

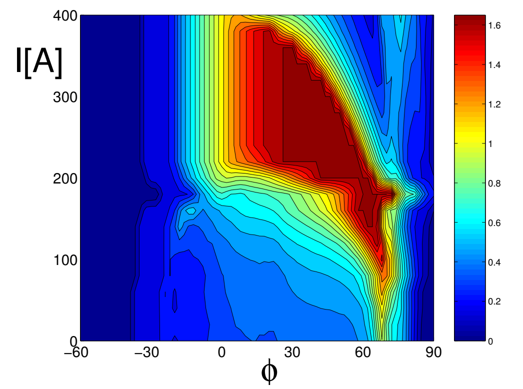

Fig. 5: *Radial profile: The simulated charge is plotted for the phase ϕ over the solenoid current. The colors describe the measured charges, ranging from 0 nC to 1.65 nC.*

B=0 and the upper parameters agreed well with the experiment for I=0 according to Eq. (**??**), a second peak appeared in the lower left corner of Fig. (**??**), that was not observed in the experiment (Fig. (**??**)). This second maximum is a result of the transversal gaussian profile.

Thus, another simulation was carried out for a radial laser profile with a newly optimized set of parameters: σ_r = 0.4 mm, Q = 1.65 nC, FWHM = 22 ps, RT = 5 ps and E_{max} = 40.23 MeV/m. Fig. (**??**) shows the simulated results, in which the second peak is suppressed.

4 Discussion

As mentioned before, the real transversal laser profile seems to resemble more to a radial than to a gaussian distribution. Fig. (**??**) and Fig. (**??**) display the emittance for the gaussian

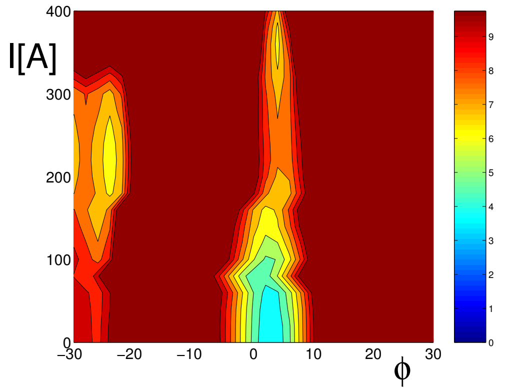

Fig. 6: *Gaussion profile: The simulated emittance is plotted for a phase ϕ over the solenoid current. The colors describe the measured emittence, ranging from 0 to 10 π mm mrad. Higher emittances are represented by the dark red colour.*

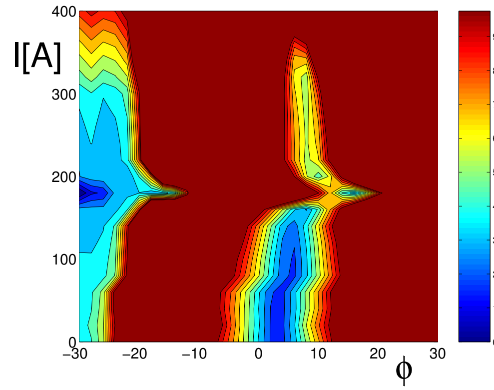

Fig. 8: *Radial profile: The simulated emittance is plotted for a phase ϕ over the solenoid current. The colors describe the measured emittence, ranging from 0 to 10 π mm mrad. Higher emittances are represented by the dark red colour.*

and the radial distribution. Both figures reveal a narrow band of low emittance close to the phase of maximum energy gain. However, it was not possible to measure the emittance during phase scans.

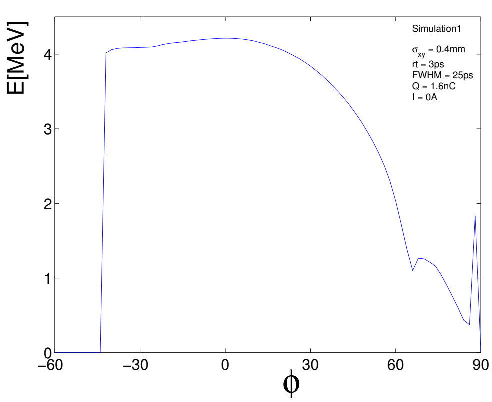

Fig. 7: *Example of an energy distribution for one phase scan using the gaussian profile.*

For an optimum setting, the emmitance should be as small as possible for a highly energetic bunch with a charge of 1nC. On the one hand, emittance is smallest for low magnetic field ($I < 100A$). On the other hand, only for high field strengths ($I > 200A$) a charge of 1 nC reaches the Faraday cup (Fig. (**??**), (**??**), (**??**)). In this region region, the emittance does not become lower than $\approx 7\pi$ mm mrad for the gaussian and $\approx 5\pi$ mm mrad for the radial transverse laser profile. This is about twice the value of the experimental emittance. Whether this is due to a lack of finetuning of the input parameters or has some principal reasons, could not be examined in the frame of this work.

Acknowledgements

This is right place to express my gratitude to Mr. Hiller, all lecturers, the PITZ group, the other summer students and everybody else, who made the stay in Zeuthen possible and enjoyable.

In particular, I would like to thank Ilja Bohnet and Mikhail Krasilnikov, who looked after me and guided the experiments. Special thanks to Dirk Lipka, who always readily answered all questions, and gave essential hints for the work.

I am deeply indepted to my fellow summerstudent Helge Todt, not only for a constant supply of chocolate, cookies and tea, but also for his 24h computer support, that surely kept me from going insane :-)

References

[1] http://desyntwww.desy.de/pitz/goals.html

[2] http://desyntwww.desy.de/pitz/pitz_function.html

[3] K.Floettmann and F.Stephan, *Proposal for the BMBF "RF Photoinjectors as a Sources for Electron Bunches of Extremely Short Length and Small Emittance"*, 1999.

[4] K.Floettmann, *ASTRA manual*, 2003.