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SYSTEMATIC BEAM PARAMETER STUDIES AT THE INJECTOR SECTION OF FLUTE

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Abstract

FLUTE (Ferninfrarot Linac- und Test-Experiment) is a compact linac-based test facility for accelerator R&D and source of intense THz radiation for photon science. In preparation for the next experiments, the electron beam of the injector section of FLUTE has been characterized. In systematic studies the electron beam parameters, e.g., beam energy and emittance, are measured with several diagnostic systems. This knowledge allows the establishment of different operation settings and the optimization of electron beam parameters for future experiments.

INTRODUCTION

At the Ferninfrarot Linac- und Test-Experiment (FLUTE) electrons are generated with a photo-injector system [1]. This system consists of a Ti:Sa laser system and an 2.5 cell S-band cavity where an electron bunch is accelerated up to 7 MeV bunch energy. The short electron bunch can then be used for experiments in the first section, i.e. the low energy section. From the low energy section the electron beam will be injected into a linear accelerator structure and further accelerated up to 41 MeV. For optimizing the system, the characterization of the beam parameters at the beginning is important. Several diagnostic systems are available for this task, for example, to measure the bunch energy, bunch charge and position [2]. In addition the laser pulses for generating electrons can be monitored. This includes an optical system to visualise the laser spot position on the photo cathode.

These diagnostic systems allow a systematic approach to investigate the influence of the laser spot position on the electron bunch parameters. In a first attempt, nine positions were investigated, with a focus on the bunch energy, bunch charge and the transverse emittance.

MEASUREMENTS

The electron beam parameters are influenced by various sources, for example, RF input power. For the investigation presented in this paper, only the influence from different laser spot positions on the cathode is studied. The settings for the RF system and laser pulses are listed in Table 1. Here, the RF phase was adjusted to the highest energy gain at the beginning of the measurement.

The laser spot movement was controlled manually by a motorized mirror in the laser path. For the nine investigated positions on the cathode a 3x3 grid was chosen around a previously optimized central point. In reference to the cathode, shown in Fig. 1, the grid (marked as dots) is offset from the cathode center (marked as black cross). The slightly deformed grid occurred due to a coarse manual mirror control.

Table 1: Measurement Settings

RF power input	9.45 ± 0.02 MW
RF phase	0[1] ± 0.4°
Laser pulse energy	87 ± 7 µJ
Laser spot width	0.2 ± 0.1 mm
Mean solenoid strength	151.6 ± 0.4 mT

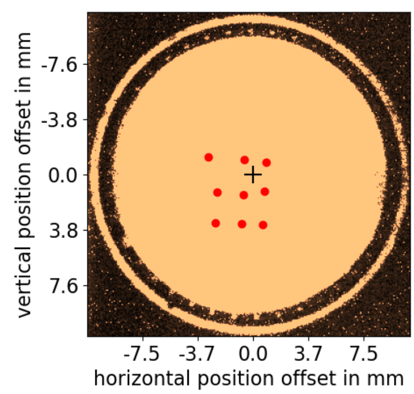

Figure 1: Laser spot positions on the cathode surface.

For the measurement of bunch energy and transverse emittance the profile monitor system in the low energy section is used [2]. These screen stations are placed at a distance of 2.86 m from the cathode, which induced the need for focussing by a solenoid magnet positioned after the gun cavity. The focussing strength was adjusted for each spot position to compensate any energy change and provide the same condition for the emittance measurement. In total a variation of 1.4 mT (equals 0.2%) of the magnetic field was needed.

Beam Energy

The beam energy was measured with the low energy spectrometer, comprised of a sector magnet, steering the electron bunch by 30° onto a screen station. Combining the magnet strength with the position on the scintillation screen, the bunch energy was determined for each laser spot position [3]. For each position at least 20 screen samples are taken. In addition to the RF settings, the energy gain is strongly influenced by the cavity temperature instability. The correlation between cavity temperature and RF phase is shown in Fig. 2.

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[1] Relative value to setting of highest energy gain.

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The correlation to the measured power inside the cavity is likewise plotted. Due to this effect a variation of bunch energy during the measurement campaign is expected.

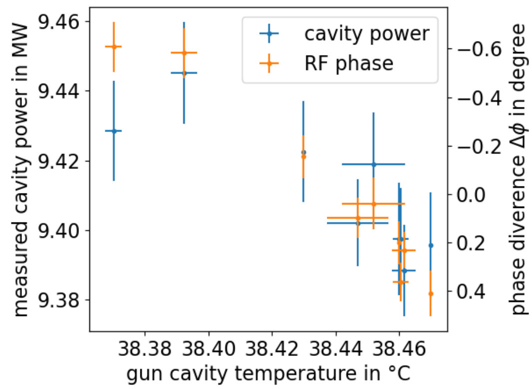

Figure 2: Temperature influence on RF parameter.

Beam Charge

The measurement data for the bunch charge was collected with the non-destructive Turbo-ICT from Bergoz [2]. A dark current suppression is part of the operation principle in the frequency domain. For each laser spot position the bunch charge was sampled at least 300 times while determining other bunch parameters. The surface quality of the copper cathode at the investigated positions is one contributor to a change in bunch charge. However, the laser pulse intensity directly influences the amount of generated electrons. Monitoring the pulse intensity during the measurements revealed a fluctuation of 8%.

Beam Emittance

For the measurement of the transverse emittance with horizontal and vertical component the quadrupole-scan method was performed [4]. The rms beam size x_s and rms beam divergence x'_s at a given position s define the trace space emittance, according to [5]:

$$\epsilon_{s,tr} = \sqrt{\langle x_s^2\rangle\langle x_s'^2\rangle - \langle x x_s'\rangle^2}. \tag{1}$$

From these parameters in a profile monitor system only the rms beam size is measurable. Therefore, the quadrupole-scan method facilitates the transport matrix **M** between the quadrupole position i and the measurement position f,

$$\mathbf{\Sigma_f} = \mathbf{M}\ \mathbf{\Sigma_i}\ \mathbf{M^T}, \tag{2}$$

with the beam matrix

$$\mathbf{\Sigma_s} = \begin{pmatrix} \sigma_{11,s} & \sigma_{12,s} \\ \sigma_{21,s} & \sigma_{22,s} \end{pmatrix}. \tag{3}$$

Equation (1) is actually the determinant of the beam matrix.

In the low energy section of FLUTE the used quadrupole is installed 1.45 meters from the cathode surface. The electron beam is detected with the profile monitor system at a distance d = 1.41 meters further from the quadrupole. The horizontal and vertical beam size have been determined from the bunch profile assuming a Gaussian distribution in both planes. This assumption works best for bunches focused on the screen. According to Eqs. (2) and (3), the relation of measured beam size and quadrupole magnet strength is [4]:

$$\begin{aligned} \sigma_{11,f} &= \sigma_{11,i} d^2 l^2\ k^2 \\ &\quad + (2dl\sigma_{11,i} + 2d^2 l \sigma_{12,i})\ k \\ &\quad + \sigma_{11,i} + 2d\sigma_{12,i} + d^2\sigma_{22,i}, \end{aligned} \tag{4}$$

introducing the quadrupole length l. The gradient k is derived from the magnetic current, which was scanned in steps of 0.2 A from -2 A up to + 2 A. In addition to the quadrupole, the radial focussing from the solenoid magnet was needed to assure a minimum bunch spot size within the possible working range of the quadrupole magnet. This also improves the analysis of the trace space emittance.

RESULTS

The results of the bunch energy and bunch charge measurements are listed for each laser spot position in Table 2. A position number was assigned to each spot, starting in the upper left of the grid. The exact position relative to the center of the cathode is given in addition. For the interpretation of the measurement results, the bunch parameters were simulated with the tracking code ASTRA [6].

Table 2: Laser Positions, Beam Charge and Energy

Pos	x (mm)[2]	y (mm)[2]	Energy (MeV)	Charge (pC)
1	-3.02	-1.24	5.483 ± 0.005	23.2 ± 2.6
2	-0.59	-1.02	5.513 ± 0.003	23.7 ± 2.8
3	0.92	-0.85	5.468 ± 0.001	21.8 ± 2.5
4	-2.41	1.18	5.515 ± 0.003	22.7 ± 2.7
5	-0.62	1.37	5.473 ± 0.003	22.3 ± 2.1
6	0.76	1.13	5.523 ± 0.002	22.6 ± 2.7
7	-2.53	3.30	5.556 ± 0.001	22.0 ± 2.5
8	-0.79	3.38	5.541 ± 0.002	23.3 ± 2.6
9	0.68	3.44	5.519 ± 0.005	25.0 ± 2.7

Starting with the bunch energy, a variation between 5.47 MeV and 5.56 MeV was measured. The calculated errors indicate an actual change of the bunch energy for each laser position. However, in the ASTRA simulation no change of bunch energy is calculated depending on the laser spot position. The main contributor to energy variation is the temperature fluctuations of the gun cavity during the measurement campaign, as shown in Fig. 2. As a result a supposed correlation between laser spot position and energy gain cannot be assumed.

Combining the results of all laser positions, the mean value of the bunch charge is 23.1 pC. However, the uncertainty for each position is above 10%. An influence of the cathode surface on the charge production is not observable,

[2] The uncertainty for each position was determined to ± 0.15 mm.

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as the bunch charge is dominated the contributions of other sources, like fluctuations of the laser pulse energy.

This leads to the third investigated parameter, the transverse emittance. In Table 3 the measured values for horizontal and vertical trace space emittance are given. The uncertainty of the emittance calculation reaches up to a factor of 20, which originates from the data of the quadrupole scan. Here, the fit to the data generates an uncertainty up to 11% on the fit parameters. By reducing the scanning step size the number of data points at the minimum spot size could be increased and thus improving the fit results. By plotting the measured values in the investigated grid, a gradient appears on the cathode. This is visible in Fig. 3 for the horizontal emittance and for the vertical emittance in Fig. 4. The measurements indicate a region for small emittance in the lower left from the cathode center for the horizontal, and upper left for the vertical component.

Table 3: Horizontal and Vertical Emittance

Pos	ϵ_x (mm mrad)	ϵ_y (mm mrad)
1	0.47 ± 0.95	0.24 ± 3.50
2	0.59 ± 0.84	0.44 ± 4.38
3	0.57 ± 0.38	0.67 ± 0.83
4	0.27 ± 1.08	0.35 ± 4.00
5	0.33 ± 0.58	0.59 ± 4.07
6	0.45 ± 0.89	0.72 ± 2.73
7	0.26 ± 1.27	0.47 ± 9.17
8	0.29 ± 2.31	0.75 ± 3.02
9	0.30 ± 1.84	0.97 ± 1.16

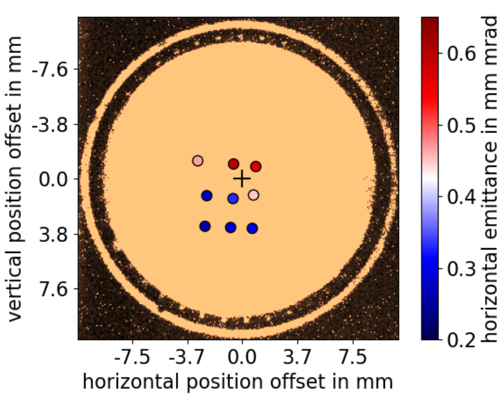

Figure 3: Horizontal emittance results.

In contrast to the measurement, the smallest emittance is simulated by ASTRA at the cathode center. This offset is likely produced by the other machine parameters, which need to be investigated further. For example, a misalignment in the camera setup for the laser spot or the solenoid magnet is possible.

CONCLUSION

At the low energy section of FLUTE systematic measurements are performed to characterize the electron bunch parameters. A first investigation concerning the influence

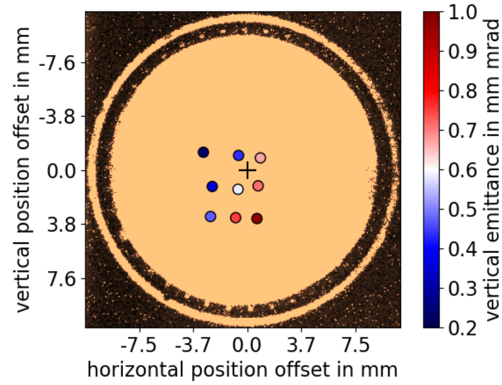

Figure 4: Vertical emittance results.

of the laser spot position on the photo cathode with respect to the bunch parameters was realized. For the bunch energy and charge the inherent fluctuations on temperature and laser pulse energy are dominant. The transverse emittance was measured with the quadrupole-scan method. The investigated 3x3 area indicates an emittance gradient on the cathode surface. Simulations, performed with ASTRA, show a differing result. A systematic offset and influences of other parameters are a possible explanation. Further investigation is needed to evaluate these influences and to reduce the fit error, to improve the emittance results.

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