ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPGW010

DIAGNOSTICS AND FIRST BEAM MEASUREMENTS AT FLUTE

T. Schmelzer*, A. Bernhard, A. Böhm, E. Bründermann, S. Funkner, B. Haerer, I. Kriznar, A. Malygin, S. Marsching, W. Mexner, M.J. Nasse, G. Niehues, R. Ruprecht, M. Schuh, N. J. Smale, P. Wesolowski, M. Yan, A.-S. Müller
Karlsruhe Institute of Technology, Karlsruhe, Germany

Abstract

FLUTE (Ferninfrarot Linac- Und Test-Experiment) is a compact versatile linear accelerator at the Karlsruhe Institute of Technology (KIT). It serves as a platform for a variety of accelerator studies as well as a source of strong ultra-short THz pulses for photon science [1]. In the commissioning phase of the 7 MeV low energy section the electron bunches are used to test the different diagnostics systems installed in this section. An example is the split-ring-resonator-experiment [2]. In this contribution we report on the commissioning status of the beam diagnostics and present first beam measurements at FLUTE.

BEAM DIAGNOSTICS

Various beam diagnostics for the measurement of the electron bunch charge, the transverse beam profile and position are installed in the low energy section of FLUTE, which is currently under commissioning [3, 4]. Before discussing the first beam measurements in this paper, an overview of the different diagnostic components are given.

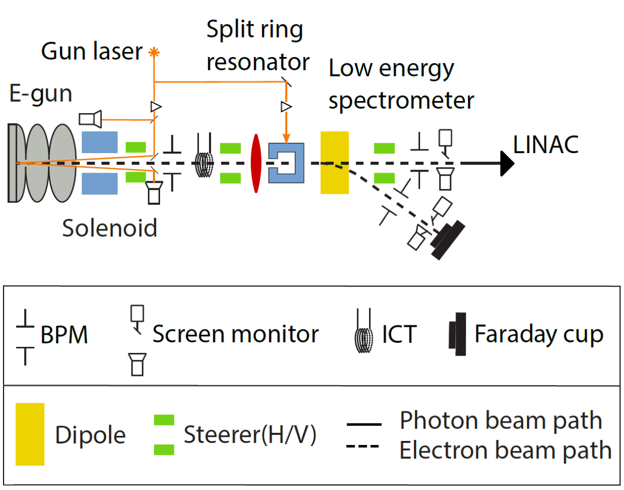

Figure 1: Schematic drawing of the low energy section, including all planned beam diagnostics. A complete overview is given in [4].

Turbo-ICT

For precise charge measurement we are using a Turbo Integrating Charge Transformer (Turbo-ICT) from Bergoz Instrumentation. This device has a sub-pC resolution and a noise floor of 10 fC rms, which is needed for the low charge operation mode of 1 pC. The Turbo-ICT is working in the frequency domain and thus suppresses signals other than the electron beam. This includes noise from electromagnetic pulses (EMP) and dark current from the e-gun, which was already verified in the commissioning of the beam diagnostics. The position of the Turbo-ICT is 1.13 m from the cathode surface of the e-gun. Depending on the settings of solenoid, laser power and RF accelerating field in the e-gun, the charge measurement reached 7 pC so far. For control and readout the company provides a LabVIEW interface, but the raw charge signal is also captured during operation.

* thiemo.schmelzer@kit.edu

Faraday Cup

A second charge measuring device in the low energy section of FLUTE is the Faraday Cup FARC-04 from RadiaBeam Technologies. For the commissioning phase of this section it is mounted instead of the linac, 3.05 m after the cathode surface. Eventually, the Faraday cup will be mounted at the end of the spectrometer pipe as it is shown in Fig. 1. The device is connected directly to an oscilloscope for the first measurements. For the charge value the integral of the signal is measured, where we obtained charges up to 5 pC.

Beam Position Monitor

In the low energy section three beam-position monitors (BPM) are installed. Two are placed in the straight beam pipe, 0.9 m and 2.61 m, after the cathode surface. To facilitate energy measurements, the third BPM is positioned 2.6 meters after the cathode in the spectrometer pipe (see Fig. 1). These cavity BPMs of type BPM38 are designed and supplied by the Paul-Scherrer-Institute (PSI) [5]. The transversal position and the charge of the bunch are provided by the readout electronics. In comparison to the other charge measurements at FLUTE the first BPM after the e-gun shows charges up to 5 pC, and around 15 % less at the downstream BPM.

Screen Monitors

In order to get information about the transversal beam profile, two screen monitor systems have been installed in the low energy section, which were used at the SwissFEL Injector Test Facility [6]. They consist of a screen holder and an optical box. The screen holder is motorized and has three slots which can be positioned in the electron path. The screens are: a cerium-doped yttrium aluminum garnet (YAG) crystal for scintillation light and an aluminum-coated silicon mirror for optical transition radiation (OTR). For the calibration of the camera system a calibration target from

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPGW010

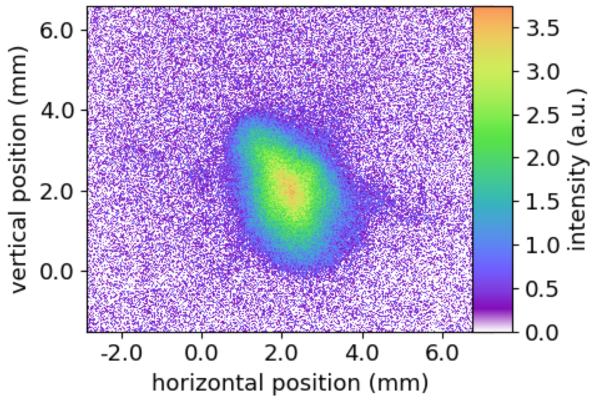

Figure 2: Zoom at one measured beam profile on the YAG screen, with removed dark current background.

Thorlabs Inc. is mounted on the screen holder as well. The screens are facing the beam axis with an angle of 45°.

In the optical box the imaging system, consisting of a camera and lens, is shielded from any background light. For the beam profiles images we use a Basler acA1300-60gm CMOS camera in combination with a 85 mm focal length lens. In Fig. 1 the position of the two screen monitors are shown. Both are placed at a distance of 2.86 m from the cathode surface. The imaging system of the screen monitor in the spectrometer pipe has been calibrated to a imaged pixel size of (30.2 ± 0.02) µm in horizontal and (28.2 ± 0.02) µm in vertical direction. In the straight beam pipe it has been calibrated to (28.3 ± 0.04) µm in both directions.

The EPICS control system at FLUTE is used for the camera communication via an IOC based on the Basler software package Pylon 5 [3]. A MATLAB tool was developed for readout and preprocessing the camera images during operation. Due to the low charge and energy in the commissioning of the low energy section, only the more sensitive YAG screen was used in profile measurements. A recent beam profile measurement is shown in Fig. 2.

Split Ring Resonator Experiment

The first experiment at FLUTE is currently under construction, based on the collaboration between PSI, University of Bern and KIT [2] and is supported by the EU-H2020-project ARIES-Trans National Access (TNA). The goal of this single-shot THz streaking experiment is to measure the longitudinal charge density of ultra-short bunches as a function of time. To achieve a compact setup a laser-generated THz pulse is focused onto a split-ring resonator (SRR), a small metal ring with a gap. This SRR leads to an intense electric field in the small gap (20 x 20 μm^2) that streaks the electrons flying through the gap transversely. After a drift section, the electrons are subsequently measured with a YAG screen and a camera. The THz pulse used to excite the SRR is intrinsically synchronized with the electrons as they are produced by the same laser pulse that also generates the accelerated electrons in the gun.

This experiment is placed in a multi-purpose chamber in front of the spectrometer dipole, 1.72 meters after the cathode. Before the measurement phase can be started, three requirements need to be satisfied: (a) The THz generation next to the experiment, (b) The positioning of the SRR structure relative to the beam, (c) Synchronization, control and stability of the electron bunches. The generation of THz pulses with the FLUTE laser system was already accomplished [7]. For the set-up next to the experiment chamber the optics are currently being built up on a moveable plate. The precise positioning of the structure is important due to the 20-µm-sized gap. A system using a guiding laser as reference point for the electron bunch will be installed. Recently, we have achieved reliable synchronization between laser and RF-pulses in cooperation with our partners from DESY.

BEAM PROFILE MEASUREMENTS

For the first measurements of the transversal beam profile, the screen monitor in the straight spectrometer beam pipe was used. The measurements were done with laser synchronization in operation and the repetition rate of the RF pulses was set to 1 Hz. The laser pulses of 50 µJ were hitting the cathode surface with 1 kHz repetition rate. The bunch charge was measured with the Turbo-ICT to 5 pC. The RF system was set to an output power of 4.2 MW, which leads to an electron energy of around 3.5 MeV. The solenoid after the e-gun was used to focus the electron beam on the YAG screen.

Measurements and Image Processing

The measurement started by capturing the dark current induced only by the RF-power in the e-gun, which is used for background noise subtraction in the image processing. After turning on the laser pulses on the cathode, electron bunches were generated. With our graphical user interface for the screen monitor, 120 beam profile images were taken to determine the position and the RMS width of the electron beam on the screen.

A region of interest (ROI) filter was used to locate the beam profile on the screen image. This uses a noise level estimation, which is done by sorting the intensity of the pixels in a histogram and fitting an asymmetric Gaussian function. The image, subtracted by the mean noise, is convoluted with a 7x7 Gaussian filter. Searching for the highest intensity entry in the filtered image gives us the area of highest intensity in the original image and thus the beam profile. As final step a mask is created by the ROI filter, to set all other pixels than the beam profile to zero. For this mask a threshold level factor is provided, which defines the beam level. A setting of 2.0 for this factor seem to be satisfactory.

Results

The mean profiles of 120 beam images are shown in Fig. 3, split in horizontal and vertical component. For further anal-

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-WEPGW010

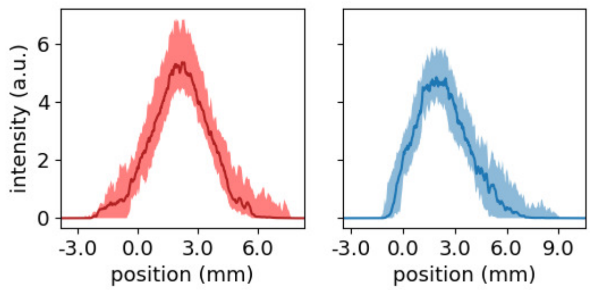

Figure 3: Horizontal (in red) and vertical (in blue) projection of the beam profiles after image processing. The mean profile is indicated as dark line. The light area spans between minimum and maximum value of the measured 120 profiles at each position.

ysis, the mean position on the screen μ and the RMS width of the profiles were calculated, using:

$$\mu = \sum_i x_i \cdot p_i \ , \quad \sigma^2 = \sum_i (x_i - \mu)^2 p_i \ , \quad RMS = \sqrt{\sigma^2} \ , \quad (1)$$

with the variance σ^2, the pixel position x_i and relative intensity p_i. The position on the screen in horizontal direction is $\mu_x = (2.06 \pm 0.09)$ mm and in vertical direction $\mu_y = (2.30 \pm 0.14)$ mm. The transversal width of the 120 profiles is (1.41 ± 0.08) mm in horizontal and (1.46 ± 0.13) mm in vertical direction. If needed the steerer magnets together with the BPMs can be used to correct the slight off-center position of the beam.

The electron beam profile strongly depends on size and shape of the laser spot used to produce the electrons. We use a lens to focus the laser to get a small spot on the cathode. Using the machine settings mentioned above and assuming a laser spot size of 0.4 mm (FWHM), the beam RMS width at the screen position was simulated to be 1.49 mm in both directions. This corresponds well to the measured profile, considering the estimations for laser spot and electron energy.

For the simulation, a Gaussian distribution was used as initial beam profile. In the experiment, the unfocused laser spot was slightly asymmetric, which can explain the skewness in the vertical profile of the electron beam. In addition, the not yet stabilized laser transport leads to intensity and position fluctuations on the cathode. This could partially be the reason for the pointing fluctuations.

SUMMARY AND OUTLOOK

The beam diagnostics in the low energy section at FLUTE are currently being commissioned. For the screen monitor system an analysis tool to determine beam profile parameters is implemented and delivers first data.

After the first profile measurements, systematic studies are planned to distinguish the beam parameters and their dependencies on machine settings. This includes energy measurements using the low energy spectrometer and the second screen monitor.

Several updates of the laser system are in progress, e.g. a virtual cathode to directly measure the laser spot size and a laser beam stabilisation system to further improve the beam stability.

ACKNOWLEDGEMENTS

The authors want to thank their colleagues from PSI, DESY and University of Bern. In particular Zoltan Ollmann for the support of the THz generation setup, Tomasz Kozak and Matthias Felber for the valuable support of the laser synchronization and Martin Hierholzer and Matthias Hoffmann for the support of the LLRF. The SRR project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871.

REFERENCES

[1] M.J. Nasse *et al.*, "FLUTE: A versatile linac-based THz source", in *Rev .of Sci. Instrum.* **84**, 2013, pp. 022705. doi: 10.1063/1.4790431

[2] M. Yan *et al.*, "Design of a Time-resolved Electron Diagnostics Using THz Fields Excited in a Split Ring Resonator at FLUTE", in *Proc. IBIC'16*, Barcelona, Spain, Sep. 2016, pp. 475–478. doi:10.18429/JACoW-IBIC2016-TUPG56

[3] M. Yan *et al.*, "FLUTE Diagnostics Integration", in *Proc. IPAC'18*, Vancouver, Canada, Apr.-May 2018, pp. 2227–2229. doi:10.18429/JACoW-IPAC2018-WEPAL029

[4] M. J. Nasse *et al.*, "First Electron Beam at the Linear Accelerator FLUTE at KIT", presented at the IPAC'19, Melbourne, Australia, May 2019, paper MOPTS018, this conference.

[5] B. Keil *et al.*, "Design of the SwissFEL BPM System", in *Proc. IBIC'13*, Oxford, UK, Sep. 2013, paper TUPC25, pp. 427–430.

[6] R. Ischebeck *et al.*, "Profile Monitors for the SwissFEL Injector Test Facility", in *Proc. LINAC'10*, Tsukuba, Japan, Sep. 2010, paper TUP103, pp. 656–658.

[7] V. Schlott *et al.*, "Status of the THz Streaking Experiment with Split Ring Resonators at FLUTE", in *Proc. IBIC'17*, Grand Rapids, MI, USA, Aug. 2017, pp. 186–188. doi:10.18429/JACoW-IBIC2017-TUPCC16