STATUS OF FLUTE

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Abstract

FLUTE, a new linac-based test facility and THz source is currently being built at the Karlsruhe Institute of Technology (KIT) in collaboration with DESY and PSI. It consists of an RF photo gun and a traveling wave linac accelerating electrons to beam energies of ~ 41 MeV in the charge range from a few pC up to 3 nC. The electron bunch will then be compressed in a magnetic chicane in the range of 1 - 300 fs, depending on the charge, in order to generate coherent THz radiation with high peak power. An overview of the simulation and hardware status is given in this contribution.

INTRODUCTION

FLUTE (*Ferninfrarot Linac- Und Test-Experiment*—farinfrared linac- and test-experiment) [1,2] is an accelerator R&D facility to study bunch compression with all related effects and instabilities e.g. space charge, CSR as well as the different generation mechanisms for coherent THz radiation in theory and experiment. It will be used as a test bench for the development of new diagnostics and instrumentation for fs bunches, as an injector test stand for laser wakefield accelerators and a study for future compact, broadband accelerator-based THz user-facilities. At the THz beam line experiments with THz pulses, e.g. pump-probe with new materials, can be carried out. In Tab. 1 the key electron beam and THz parameters are summarized.

Table 1: FLUTE electron beam and THz parameters

Parameter	**Value**	**Unit**
Final electron energy	~ 41	MeV
Electron bunch charge	1 – 3000	pC
Electron bunch length	1 – 300	fs
Spectral bandwidth	~0.1 – 100	THz
THz pulse power	up to ~ 5	GW
THz pulse energy	up to ~ 3	mJ
THz E-field strength	up to ~ 12	MV/cm
Pulse repetition rate	10	Hz

LAYOUT

FLUTE will be installed in an existing building. Its layout and the most compact accelerator design (~ 15 m) with minimized THz transport distance is shown in Fig. 1. All components will be installed on a modular girder structure to provide maximum flexibility. Hence, extensions like a buncher cavity, as studied in [3], can be integrated without major reconstruction. Between the main components dedicated diagnostic sections are planned. The machine length is limited to about 20 m because of the bunker size.

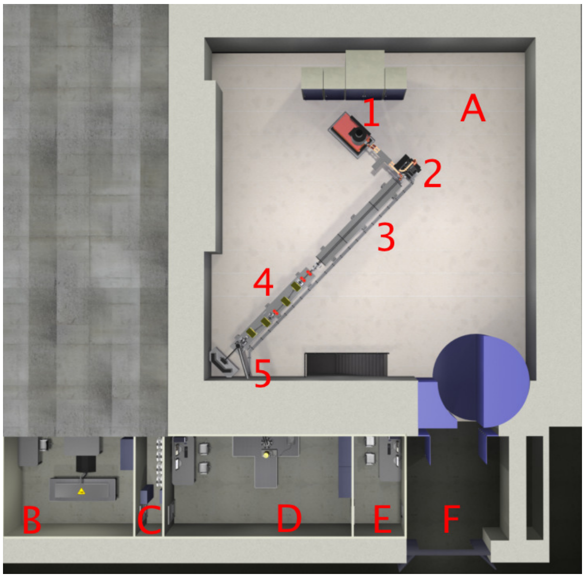

Figure 1: Layout of the FLUTE building. Bunker (A): klystron with auxiliaries (1), gun with solenoid (2), linac (3), bunch compressor (4), THz beam line (5), laser clean room (B), airlock(C), experimental room (D), control room (E), entrance area (F).

Two meters of concrete provide sufficient shielding and allow unrestricted access to the rooms adjacent to the bunker. The gun laser system is installed in a temperature ($21 \pm 1^\circ$ C) and humidity (<45%) stabilized ISO class 6 clean room. It is separated by an airlock from the experimental room with the THz beam line and a T-shaped optical table for different experiments. The machine control room is next to the experimental room.

SIMULATIONS

The tracking codes ASTRA [4] und CSRtrack [5] have been used to design and optimize the accelerator layout and settings in order to minimize the RMS bunch length [6,7]. Further optimization is ongoing especially in the 1 pC charge regime. Latest results show an electron bunch length reduction from 13 fs to 5 fs if the RMS laser pulse length is reduced from 1 ps to 0.5 ps and the transverse laser spot size

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is increased at the same time. The electric field of the THz pulse generated with this electron bunch is discussed in a dedicated contribution [8].

Start-to-end simulations are currently carried out using ASTRA in order to perform a stability analysis of all components and identify critical parameters as function of the different charge operation regimes. So far, the most critical parameter is the laser timing error with respect to the RF phase. This error is the sum of all errors from the laser synchronization, pulse generation and transport. The correlation between the timing error and the compressed RMS bunch length is shown in Fig. 2 for a 1 pC bunch. A timing error results in an error in energy and energy spread which leads to a mismatched beam in the bunch compressor. The origin of the fluctuations around the reference value are subject to further investigation. Based on this data a timing stability better than ±200 fs is required.

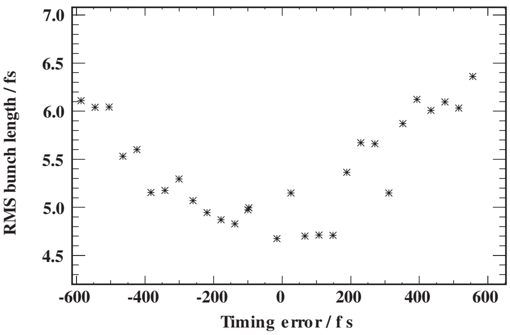

Figure 2: RMS bunch length as function of the timing error for a 1 pC bunch. The bunch length increases significantly for timing errors larger than ±200 fs and shows fluctuations in the order of 0.5 fs around zero.

LASER

We will use a commercial short-pulse Ti:Sa laser consisting of a high-power oscillator and a regenerative amplifier. The laser system will deliver 35 fs pulses with an energy of 5 mJ per pulse. The oscillator features a motor- and piezo-based cavity length adjustment system. Thus, the laser repetition rate of 83.276 MHz can be synchronized to the master clock. The oscillator offers an average power of 750 mW so that part of the pulses can be coupled out via a beam splitter to be used for other purposes, e.g., for pump-probe experiments or laser-based electron beam diagnostics. A pulse-picker will reduce the kHz amplifier repetition rate to 10 Hz (mains-synchronized), the operation repetition rate of FLUTE. A third-harmonic unit will subsequently produce pulses with 400 and 266 nm wavelength from the fundamental 800 nm laser output. We plan to use a pulse-stretcher to obtain UV pulses in the range of 0.5 - 4 ps (RMS). The UV pulses will then be transmitted into the bunker to the photocathode. At a later phase, if necessary, we will install a feedback system to reduce the impact of drift and vibrations from the 35 m long transport path of the laser beam. Additionally, a laser arrival time monitor could compensate for laser timing errors.

RF-SYSTEM

A 45 MW S-band klystron is used to power the gun and the DESY type traveling wave linac. The power is divided by a remotely controlled power splitter based on 3 dB hybrids and a phase shifter. An additional phase shifter and a circulator is installed in front of the gun in order to adjust the phase individually and reduce the crosstalk between the structures and the reflections out of the gun. Several directional couplers are planed to measure the forward and reflected power of the klystron, gun, and linac. In the circulator SF_6 is required as isolation gas. Hence, SF_6 is used in the complete waveguide system. All waveguide components are delivered and currently prepared for the assembly. Details of the LLRF system are discussed in [9].

RF PHOTO GUN

The RF photo gun foreseen for FLUTE was designed and operated in CTF II at CERN [10]. It consists of 2.5 cells and is optimized for high charge beams. Cu cathodes will be used in the start phase and later cathode materials like CsTe to generate bunches with several nC. In 2013 first successful high power tests were carried out at ELSA in Bonn [7] to start the recommissioning of the gun. Additional RF measurements have been carried out including bead pull measurements. The following parameters are measured and summarized in Tab. 2: resonance frequency f, unloaded quality factor Q_0, shunt impedance ZT^2. They are in good agreement with [10]. In Fig. 3 the average field profile is shown based on several bead pull measurements at different temperatures and using different beads. All cells are equipped with piston tuners which can be used to tune the single cell resonance frequency and optimize the E-field profile further if required. The measured field profile is used in ASTRA to improve the simulation model of the machine.

Table 2: Gun measurement results

Parameter	**Unit**	**Value**	**Error**	**Ref [10]**
f(26° C)	MHz	2998.082	0.002	$2998.55^{\dagger}$
f(33° C)	MHz	2997.750	0.010	$2998.55^{\dagger}$
Q_0		14700	1500	14000
ZT^2	MΩ/m	12.5	2.8	14.13

† design value

DIAGNOSTICS AND CONTROL SYSTEM

The main R&D topics of FLUTE - to study both, a large charge range, and get down to very short pulses - put great demands onto the diagnostics devices and the control system.

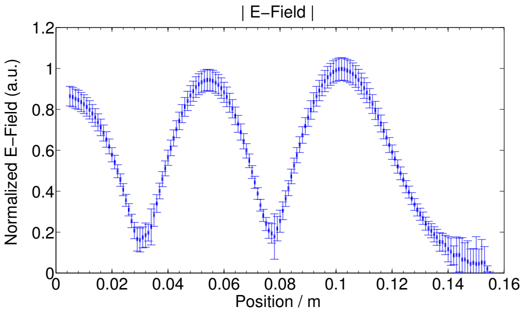

Figure 3: Measured E-Field profile of the 2.5-cell gun using a bead pull set up. It is normalized to maximum. The cell to cell field flatness is about 90%.

The electron beam diagnostics will feature diagnostics devices like fluorescence screens to measure the beam size, a Faraday cup and an integrating current transformer for bunch charge measurements, cavity BPMs (SwissFEL 38 mm design, see [11]) for the beam position, and electron energy spectrometers before and after the linac to monitor the electron energy and the energy spread. Additionally, a quadrupole triplet in combination with fluorescence screens is foreseen for emittance measurements. A bunch length monitoring system based on the electro-optic technique of spectral decoding (EOSD) [12] using an Yb-doped fiber laser system (central wavelength 1030 nm) [13] and a GaP crystal is proposed. The possibilities to use such a system at different positions in FLUTE for different currents is explored in an dedicated contribution [14]. At the end of the machine, dedicated space will be allocated for tests of new diagnostics devices such as future BPMs, bunch arrival monitors and so on. For the THz beam several diagnostics devices in the time and frequency domain are planned, such as grating-, Martin-Puplett- and Michelson interferometers, fast THz detectors and far-field electro-optical techniques.

In order to study the various mechanisms influencing the final THz pulses, data-acquisition and storage systems are required that allow for the correlation of beam parameters on a per-pulse basis. A modern, EPICS-based control system [15] is being developed. This control system combines well-established techniques (like S7 PLCs, Ethernet, and EPICS) with rather new components (like MicroTCA, Control System Studio, and NoSQL databases) in order to provide a robust, stable system, that meets the performance requirements.

SUMMARY

FLUTE is a linac-based broad band THz source and R&D facility currently under construction. It addresses all aspects for the generation and detection of fs bunches as well as the THz emission of these bunches. Simulations show potential of further bunch length reduction and critical parameters for the bunch length stability have been identified. Due to the wide parameter range which will be covered and a modular design it is perfectly suited as test facility for diagnostics and novel concepts. The nest step is the assembly of the RF system and to continue the gun commissioning at KIT.

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REFERENCES

[1] M.J. Nasse et al., Rev. Sci. Instrum. **84**, 022705 (2013).

[2] M.J. Nasse et al., "FLUTE: A versatile linac-based THz source generating ultra-short pulses", IPAC'13, Shanghai, China, June 2013, WEPWA010.

[3] M. Schuh et al., "RF Bunch Compression Studies for FLUTE", IPAC'13, Shanghai, China, June 2013, WEPWA019.

[4] K. Floettmann, "ASTRA: A Space Charge Tracking Algorithm, Version 3.0" (2013), http://www.desy.de/ mpyflo

[5] M. Dohlus and T. Limberg, "CSRtrack" (2013), http:// www.desy.de/xfel-beam/csrtrack

[6] S. Naknaimueang et al., "Simulating the Bunch Structure in the THz Source FLUTE", IPAC'13, Shanghai, China, June 2013, WEPWA008.

[7] S. Naknaimueang et al., "Optimization of the Beam Optical Parameters of the Linac-based Terahertz Source FLUTE", FEL2013, New York, NY, USA, August 2013, WEPSO44.

[8] M. Schwarz et al., "Analytic Calculation of Electric Fields of Coherent THz Pulses", IPAC'14, Dresden, Germany, June 2014, MOPRO067, These Proceedings.

[9] M. Hoffmann et al., "High Speed Digitial LLRF Feedbacks for Normal Conducting Cavity Operation", IPAC'14, Dresden, Germany, June 2014, WEPME066, These Proceedings.

[10] R. Bossart et al., "A 3 GHz photoelectron gun for high beam intensity", CERN, 1995, CLIC-Note-297.

[11] B. Keil et al., "Design of the SwissFEL BPM System", IBIC'13, Oxford, UK, 2013, TUPC25.

[12] B. Steffen, "Electro-Optic Methods for Longitudinal Bunch Diagnostics at FLASH," Ph. D. thesis, University of Hamburg, Hamburg, Germany, 2007.

[13] F. Müller et al. , "Ytterbium fiber laser for electro-optical pulse length measurements at the SwissFEL," in Proceedings of DIPAC'09, Basel, Switzerland, 2009.

[14] A. Borysenko et al., "Electro-Optical bunch length monitor for FLUTE: layout and simulations", IPAC'14, Dresden, Germany, June 2014, THPME123, These Proceedings.

[15] Experimental Physics and Industrial Control System (EPICS), http://www.aps.anl.gov/epics/