COMMISSIONING STATUS OF FLUTE

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

Abstract

FLUTE (Ferninfrarot Linac- Und Test-Experiment) is a new compact versatile linear accelerator at the Karlsruhe Institute of Technology (KIT). Its primary goal is to serve as a platform for a variety of accelerator studies as well as to generate strong ultra-short THz pulses for photon science. The actual assembly of the project, which includes the RF photo-injector providing electrons at beam energy of 7 MeV and a corresponding diagnostics section, is currently being commissioned.

In this article, we report on the latest progress of the commissioning phase. The status of the gun conditioning is given, followed by an overview of the RF and laser system.

INTRODUCTION

FLUTE [1, 2] is an accelerator R&D facility for the study of bunch compression with all related effects and instabilities like space charge, coherent synchrotron radiation (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. Furthermore it will serve as an injector test stand for laser wakefield accelerators, as an injector for the c-START compact storage ring [3], and to 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 Table 1 the key design parameters for the electron beam and THz radiation are summarized.

Table 1: FLUTE Electron Beam and THz Parameters

Quantity	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 E-field strength	up to ~ 1200	MV/m
Pulse repetition rate	10	Hz

FLUTE LAYOUT

FLUTE's compact layout is shown in Fig. 1. Components are installed on a modular girder structure to provide maximum flexibility. Hence, extensions like a buncher cavity, as studied in [4], can be integrated without major reconstruction. Dedicated diagnostic sections are and will be installed between the main components. The length of the final machine is around 20 m. The FLUTE experimental hall (Fig. 1: A) with two meters of concrete provide sufficient shielding and allow unrestricted access to the adjacent rooms during operation. The laser system is installed in a temperature (+/- 1 K) and humidity (< 45%) stabilized ISO class 6 clean room.

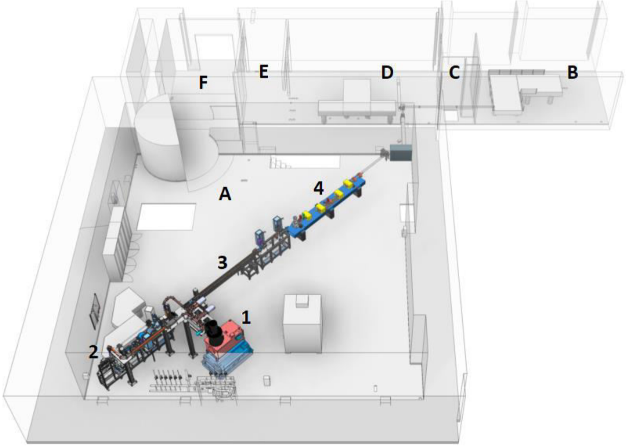

Figure 1: Layout of FLUTE: Experimental hall (A): 1 – klystron with auxiliaries, 2 – RF photo-injector with solenoid, 3 – linac, 4 – bunch compressor; laser clean room (B), airlock (C), THz measurement room (D), control room (E), entrance area (F).

COMMISSIONING OF FLUTE

In Fig. 2 the layout and a photo of FLUTE status are shown. It includes the following main components: 45 MW 3 GHz klystron and auxiliaries, RF electron photo-injector with a solenoid and electron beam diagnostics, which is described in more detail in [5]. The main goal of at stage is commissioning of the RF electron gun to produce 7 MeV electron beam and testing of the electron beam diagnostics.

Photo-cathode Laser

A commercial ultra-fast titanium sapphire laser system (Coherent Astrella, 800 nm central wavelength, nominal 35 fs pulse length, 6 W average power, 1 kHz repetition rate) is used to drive the photo-injector RF gun. The simplified layout of the FLUTE laser system is shown in Fig. 3. This infrared laser has been modified by Coherent in two points: 1 – the so-called dither piezo was not mounted providing lower phase noise and 2 – the uncompressed laser pulses (roughly 200 ps) are coupled out by

---

* anton.malygin@kit.edu

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPMF068

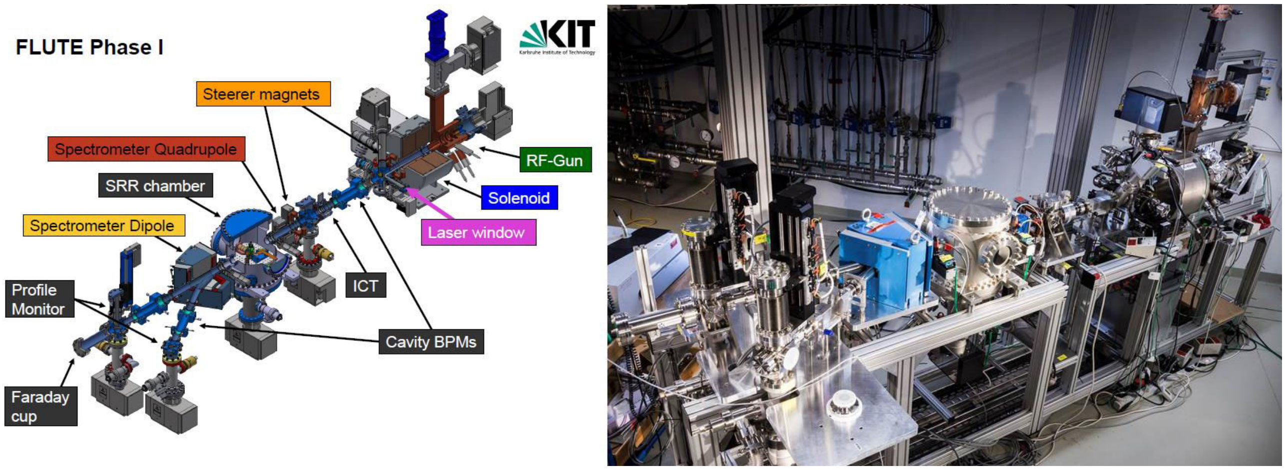

Figure 2: 3D drawing and photo of FLUTE status.

mounting an additional mirror in front of the compressor. These uncompressed infrared pulses are transported to the experimental hall over a distance of around 35 m. The laser beam is directed onto an optical table placed next to the electron gun. The first main element on this table is a pulse picker based on Pockels cells reducing the repetition rate from 1 kHz to the FLUTE operating repetition rate of 10 Hz. This is done close to the gun because in the future we are planning to set up a position feedback and stabilization system to reduce the impact of vibrations. Then the beam is sent to an external grating compressor, where the pulses are compressed to around 35 fs. This is necessary to obtain a good efficiency of >15% in the subsequent third harmonic generator producing UV pulses centred around 266 nm wavelength. We decided to transport the uncompressed pulses over the long distance and do the final compression close to the gun for several reasons. This reduces significantly the power density per pulse leading to fewer nonlinear effects over the transport distance (currently in air) so that we obtain shorter pulses with a cleaner spectrum at the end. It also allows an independent optimization of the pulse lengths for the gun and for the planned laser-based THz generation for the split-ring resonator experiment currently being set up at FLUTE [6]. The UV laser pulses are then stretched again using quartz rods of various lengths to obtain the pulse lengths needed for generating the electrons at the cathode. For the initial experimental phase Cu cathode will be used. The attainable charge is limited by the generation of plasma, which leads to damage of the cathode surface. For Cu this threshold is around 1 GW/cm^2 [7]. At a later phase, to reach higher bunch charges, Cs_2Te cathode will be used.

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 and a phase shifter which is installed between the linac and power splitter. A circulator is installed in front of the RF gun in order to reduce the crosstalk between the structures and the reflections out of the RF gun. Several directional couplers are installed in order to measure the forward and reflected power of the klystron, gun, and linac.

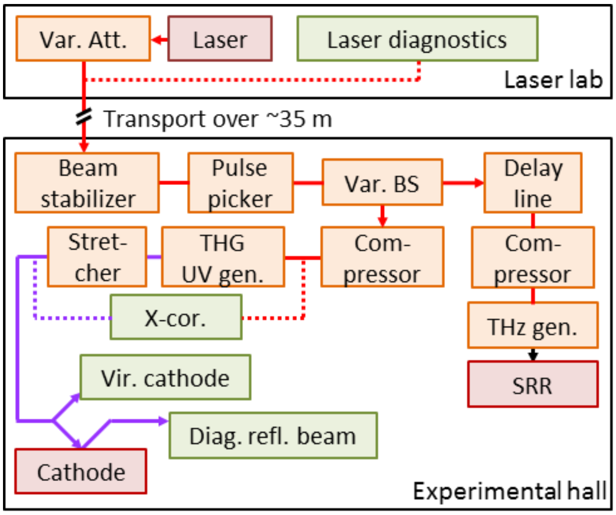

Figure 3: Simplified layout of the FLUTE laser system. Abbreviations: BS = beam splitter, THG = third harmonic generator, SRR = split ring resonator [6], X-cor. = cross correlator. Diagnostics systems are displayed in green, the source and end points (laser, SRR, photo-injector gun cathode) are shown in dark red. Dashed lines denote optional/temporal measurements.

Control and Low-Level RF System

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. An EPICS-based control system [8] is being developed. This control system combines the following well-established techniques like S7 PLCs, Ethernet, μTCA, Control System Studio, and NoSQL databases. The LLRF system used for FLUTE is based on µTCA architecture [9] and is designed by DESY. More details on the LLRF system are discussed in [10].

RF Photo-Injector Gun

The RF photo-injector gun used at FLUTE was designed and operated at CTF2, CERN [11]. It consists of 2.5 cells and is optimized for high charge beams (bunch trains with up to 13 nC per bunch). For an input power of 20 MW, the nominal gradient is 100 MV/m and the energy of the electrons at the end of the gun is 7 MeV. Each cell has an RF probe pick-up, and frequency tuners are available on each cell. To maintain a transverse beam size smaller than the iris diameter at the linac entrance the beam is focused directly after the gun with a solenoid magnet.

The low signal parameters of the RF gun were measured using a calibrated two port network analyser Keysight E5071C. The RF measurements showed that the main mode is a π-mode, which means it has 180 degrees phase advance between each cell and a resonance frequency (measured at room temperature of 25 °C) of f_{main} = 2.9983 GHz. The two closest modes have the following frequencies: 1 – f = 2.9672 GHz with 180 degrees phase advance between the first and the second cell, and 0 degrees phase advance between the second and the third cell, and 2 – f = 2.9185 GHz with 0 degrees phase advance between each cell.

The measurements of the dependence of the resonance frequency for the main mode on the cooling temperature showed that changing the temperature by 1 °C changes the resonance frequency by 48 kHz, which is sufficient to match the master oscillator frequency and minimize RF power reflection from the gun. The RF tuners in each cell have been used to optimize the field amplitudes to obtain an equal field distribution in all cells.

Before high power experiments were started the RF gun was baked-out with a temperature of 150 °C for several days for the initial outgassing. A vacuum of $3\cdot10^{-9}$ mbar has been achieved. The conditioning of the RF gun has started with a low power (~50 kW) with a pulse length of 3 µsec and a repetition rate of 1 Hz. RF power measurements showed that the circulator installed between the splitter and the RF gun has an increased loss of 1.7 dB instead of 0.2 dB according to the specifications, and therefore has to be replaced. After 100 hours of conditioning an RF power of 3 MW with a pulse length of 3 µsec and a repetition rate of 1 Hz has been reached. Example of the input power from the klystron and the signal from the RF probe pick-up connected to the first cell of the photo-injector gun is shown in Fig. 4. The modulator for the klystron was optimized for the operation above 10 MW RF power, and for lower RF power operation (Fig. 4) shows decreasing of the RF power (from 4.5 µs to 6.5 µs) after reaching the maximum power. The commissioning of the RF electron gun is in progress and the latest results will be presented at the conference.

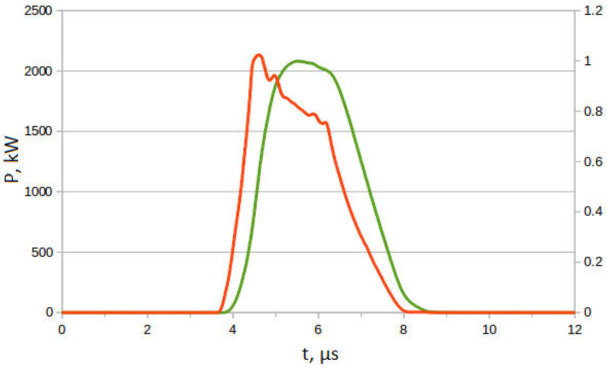

Figure 4: Input power from the klystron (red line – left axis) and normalised signal from the RF probe pick-up from the first cell of the RF gun (green line – right axis).

SUMMARY AND OUTLOOK

The assembly of the FLUTE for 7 MeV electron acceleration and diagnostic has been completed and the conditioning has started. The main goal for this experimental stage is to reach 20 MW input power for the RF gun, produce an electron beam with energy of 7 MeV, and to proof the radiation shielding of the building. Also an evaluation of the beam diagnostic [5] has to be performed. The next steps after the commissioning of the RF electron gun and the beam diagnostics system include the commissioning of the linac and the RF distribution system for the linac. This includes optimization and commissioning of the phase shifter and power splitter in order to reach maximum electron beam energy. Then the assembly and commissioning of the bunch compressor (Fig. 1) will follow, which will allow to reach the design parameters for the electron beam shown in Tab. 1.

ACKNOWLEDGEMENT

The authors would like to thank our colleagues, in particular from the Paul Scherrer Institute (PSI) and DESY, for their support and fruitful discussions on operation and installation of the FLUTE RF, control and LLRF systems.

REFERENCES

[1] M.J. Nasse *et al.*, *Rev. Sci. Instrum.*, vol. 84, 022705, 2013.
[2] M.J. Nasse *et al.*, *IPAC'13*, Shanghai, 2013, WEPWA010.
[3] A. Papash *et al.*, *IPAC'17*, Copenhagen, 2017, TUPAB037.
[4] M. Schuh *et al.*, *IPAC'13*, Shanghai, 2013, WEPWA019.
[5] M. Yan *et al.*, *IPAC'18*, Vancouver, WEPAL029.
[6] M. Yan *et al.*, *IBIC'16*, Barcelona, TUPG56.
[7] Metallic photocathodes, 2013, `http://photoinjector.web.cern.ch/photoinjector/Metallique.htm`
[8] Experimental Physics and Industrial Control System (EPICS), `http://www.aps.anl.gov/epics/`
[9] S. Jamieson. Micro Telecommunications Computing Architecture short form specification. Technical report, 2006.
[10] M. Hoffmann *et al.*, *IPAC'14*, Dresden, 2014, WEPME066.
[11] R. Bossart *et al.*, "A 3 GHz photoelectron gun for high beam intensity", CERN, 1995, CLIC-Note-297.