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FIRST ELECTRON BEAM AT THE LINEAR ACCELERATOR FLUTE AT KIT

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Abstract

The first electron beams were generated in the 7 MeV section of the short-pulse linear accelerator test facility FLUTE (Ferninfrarot Linac- Und Test-Experiment) at the Karlsruhe Institute of Technology (KIT). In this contribution we show images of the electron beam on a YAG-screen (yttrium aluminum garnet) as well as signals from an integrating current transformer (ICT) and a Faraday cup. Furthermore, the progress of tuning the FLUTE electron bunches for experiments is presented.

INTRODUCTION

The Karlsruhe Institute of Technology (KIT), in close collaboration with DESY (Hamburg, Germany) and PSI (Villigen, Switzerland), is currently commissioning the low energy section of the 41 MeV linear accelerator FLUTE (Ferninfrarot Linac- Und Test-Experiment). FLUTE is designed as a dedicated test facility for accelerator physics and technology, as well as a broadband, short-pulse source for intense THz radiation [1, 2]. One particular goal is to test and develop novel, compact diagnostics systems for future accelerators, especially for ultra-short bunches (fs or even sub-fs). For example, as the first experiment at FLUTE we are implementing a split-ring resonator (SRR) THz-streaking test setup as a compact station for the longitudinal bunch charge profile measurement [3–5]. This experiment is a close collaboration between PSI (Villigen, Switzerland), the University of Bern (Bern, Switzerland) and KIT. It is partially supported by the European Union's Horizon 2020 ARIES Trans National Access program. For more details, see also [6].

The planned layout of the entire accelerator is shown in Fig. 1. The low energy section from the gun to the first spectrometer with a nominal energy of 7 MeV is operational and is being commissioned. This section mainly consists of: the photo-injector gun, a solenoid magnet for focusing of the generated electron beam, a first BPM (beam position monitor), an ICT (integrating current transformer) to measure the charge, a set of steering magnets, a quadrupole magnet (planned to be used later for the energy spectrometer), the split-ring resonator chamber, a dipole magnet later to be used as spectrometer, another set of steering magnets and BPM, and finally a screen station (see also Fig. 1 in [6]). Currently, the straight beam pipe in this section ends with a Faraday cup behind the screen station without connection to the linac.

FIRST ELECTRON BEAM

In this low energy section, first laser-driven electrons were recorded in May 2018 using the Ce:YAG-screen (cerium-doped yttrium aluminum garnet) in the straight beam pipe (see Fig. 2), the ICT and the Faraday cup (not shown). These first measurements were performed without a closed low-level radio frequency (LLRF) loop with an RF-power of around 3 MW in the gun. In addition, the laser-to-RF synchronization was very coarse: we only synchronized the amplifier pulse picking of the laser oscillator pulses to the 3 GHz-RF-power envelopes. In this way we could only make sure that the laser pulse arrived somewhere within the RF-pulse envelope that has a duration of around 4.5 µs, but there was no reproducible correlation with the RF phase. Thus, the correct phase was only randomly hit leading to an intermittently accelerated electron bunch.

Commissioning Progress

Since then the commissioning has continued, partly in automated mode, reducing the dark current significantly:

- The circulator with a high insertion loss of −1.7 dB was replaced with a new one with a significantly lower insertion loss of −0.14 dB.
- In collaboration with DESY we closed the LLRF loop. This led to a lower RF-power noise and a flat-top signal on all gun cavities.
- The laser-to-RF synchronization was successfully implemented with the support of DESY, so that the laser oscillator cavity is actively controlled via a slow motor-based and a fast piezo-based feedback loop. This led to a phase-locking of the laser pulse to the 3 GHz-RF phase, so that we generate accelerated electron bunches reproducibly. The laser-to-RF timing jitter dropped to around 110 fs (0.03% of a 3 GHz-RF cycle).
- The RF-power noise was considerably reduced from around 2.2% down to 0.16% by synchronizing with the 50 Hz line-voltage and re-cabling of the klystron heater supplies and grounds, see Fig. 3.

Recent Results

After these improvements, we can generate *repeatable* laser-induced electron bunches reliably. A recent YAG-screen image can be found in [6]. The electron bunches with a charge of a few pC in the following examples were

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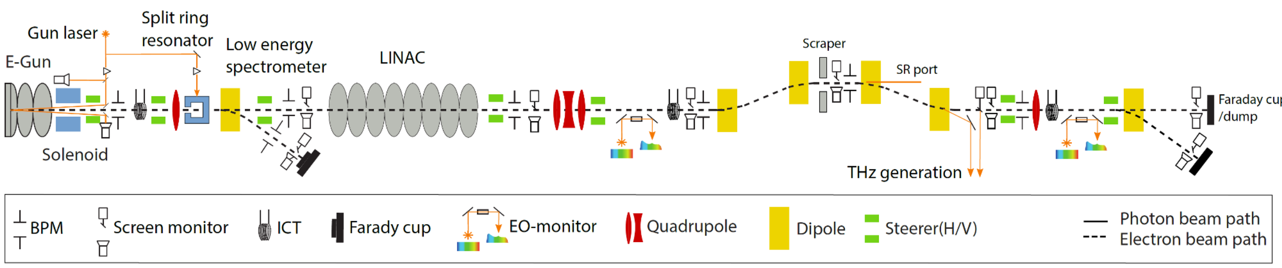

Figure 1: Schematic overview of the FLUTE layout showing the diagnostics and magnets. Currently the low energy section up to the first spectrometer is operational. Instead of the linac module, a Faraday cup is currently mounted on the straight beam pipe for charge measurements. See also Fig.1 in [6].

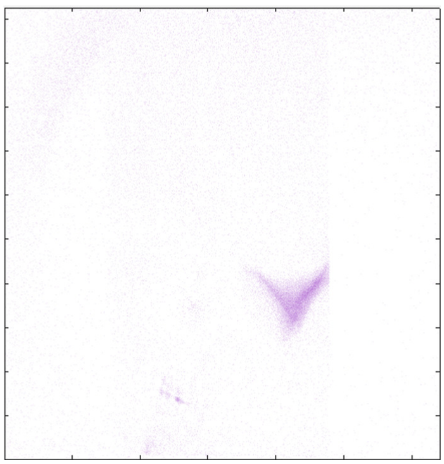

Figure 2: First measured electron beam at FLUTE on a YAG-screen, recorded with a camera (1282 × 1026 pixel) on May 3rd, 2018. Here, the background with the dark current (laser off) was subtracted.

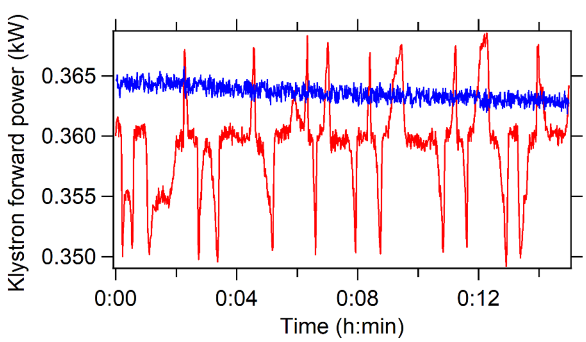

Figure 3: The klystron forward power is shown as a function of time before (red) and after (blue) the synchronization with the AC mains power and re-cabling of the klystron heater supplies and grounds.

generated with a UV laser pulse energy around 50 µJ hitting the copper cathode and then accelerated with a klystron forward power of 9.7 MW. The solenoid current for focusing was 54 A. The bunches have an energy of around 5.3 MeV. Figure 4 shows a typical measurement of the upstream BPM, the ICT and the Faraday cup signals at the end of the low energy section, recorded with a 4 GHz-oscilloscope. The Q (charge) BPM band corresponds to the envelope of the RF-pulse, the narrow spike on top is from the laser-driven electron bunch. The peak in the raw, analog ICT signal and the charging curve from the Faraday cup are also visible.

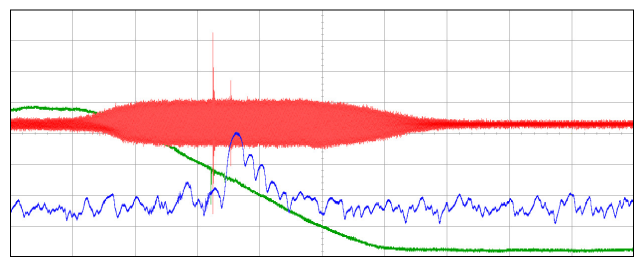

Figure 4: Oscilloscope screenshot (500 ns/div) showing the Q out signal from the first BPM (red, horizontal), the raw ICT (blue curve), and the Faraday cup signal (green line). The short spike on the BPM signal corresponds to the laser-induced electron bunch, also visible as peak on the ICT signal.

Figure 5 gives another example of the raw and processed ICT signal. The latter is produced by a capture and hold circuit. The trend of the processed signal is also plotted, and its peak height corresponds to the bunch charge, which we used to generate the histogram shown as bar diagram. The high, narrow peak on the right side of the histogram comes from laser-induced electron bunches, the broader peak on the left side stems from electronic noise, recorded with the laser off. Both cases laser-off and -on are very well separated.

Figure 6 shows a typical Faraday cup signal. In contrast to the ICT and the BPM Q-signal, which both allow the quantitative measurement of only the laser-driven electron bunches, the Faraday cup always measures the total charge: laser-induced and dark current. Since the dark current increases nonlinearly with the RF-power we decreased the klystron power for this measurement to 6.6 MW (resulting electron energy: 4.3 MeV) to increase the separation of dark current and laser-driven signal. For this decreased RF-power we obtain a good separation of the charge measured with laser on and off shown in the histogram of the Faraday cup signal in Fig. 6. We attribute the slight asymmetry of the peaks to small changes in vacuum pressure during the measurement process.

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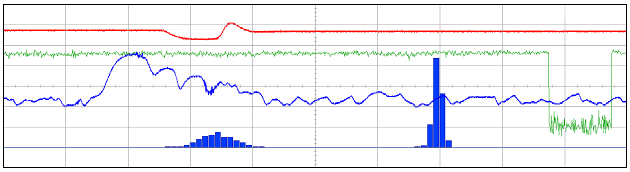

Figure 5: Oscilloscope screenshot (200 ns/div) showing the raw, analog (blue, 3rd curve from top) and processed (capture & hold) ICT signal (red, top curve). The trend of the processed ICT signal is drawn in green (2nd from top), the drop on the right side corresponds to laser off. The peak/pattern of the analog signal corresponds to the laser-driven electron bunch. Also, the histogram of the processed ICT signal is displayed as blue bar plot (bottom).

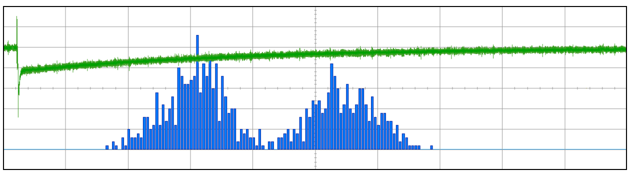

Figure 6: Oscilloscope screenshot (200 µs/div) showing the signal from the Faraday cup (green). The histogram is displayed in blue. The left peak corresponds to charge from laser-induced electrons, the right peak from dark current. In contrast to the other plots, this measurement was recorded with a klystron forward power of only 6.6 MW leading to an electron energy of 4.3 MeV.

CONCLUSION AND OUTLOOK

The low energy section of the linear accelerator FLUTE generates electron bunches *repeatably*, currently with a charge of a few pC and an energy of about 5.3 MeV. This will improve in the near future as commissioning is still ongoing. The LLRF and the laser-to-RF synchronization is working and bunches can be produced reliably with a repetition rate of 1 Hz. The SRR assembly is currently being finished. All magnets for the entire accelerator arrived and the last ones are being characterized at KIT. The diagnostics section after the linac is completed and vacuum-tight. After finishing the commissioning of the low energy section the next steps include connecting and commissioning of the linac and the corresponding RF distribution system, as well as finishing the design and the assembly of the bunch compressor and THz beamline.

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