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STATUS OF THE FLUTE RF SYSTEM UPGRADE

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Abstract

FLUTE (Ferninfrarot Linac- Und Test-Experiment) is a compact versatile linear accelerator at KIT. Its main goal is to serve as a platform for a variety of accelerator studies as well as a generation of strong ultra-short THz pulses for photon science. Also, it will be used as an injector for a Very Large Acceptance compact Storage Ring (VLA-cSR) which is being realized at KIT in the framework of the compact STorage Ring for Accelerator Research and Technology (cSTART) project. To achieve acceleration of electrons in the RF photo-injector and linac with high stability, it is necessary to provide stable RF power. For this goal, an upgrade of the existing RF system design was proposed and is currently being implemented. In this contribution an updated RF system design and the status of the RF photo-injector, linac and bunch compressor commissioning will be reported.

INTRODUCTION

Experimental studies of Compact Transverse Deflecting system [1-3], studies of coherent THz radiation and injection to cSTART requires high stability of the electron beam. In order to achieve high stability, the new RF system was designed, build and tested. As seen in Fig. 1 the new RF system includes the following major components: RF photo-injector, modulator and klystron for the RF photo-injector (K100 RF unit), linac, modulator and klystron for the linac (K300 RF unit), new waveguide systems for both RF photo-injector and the linac.

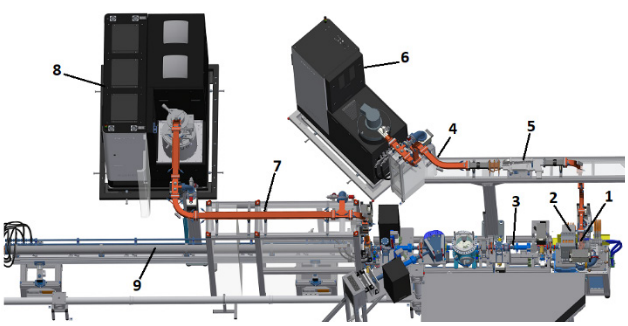

Figure 1: new RF system layout: 1 – RF photo-injector, 2 – solenoid, 3 – diagnostic after the RF photo-injector, 4 – vacuum waveguide, 5 – circulator (filled with SF6 gas), 6 – modulator and klystron for the RF photo-injector (K100 RF unit), 7 – fully vacuum waveguide for the linac, 8 – modulator and klystron for the linac (K300 RF unit), 9 – linac.

The RF commissioning of the RF photo-injector allowed to achieve the design goals. Linac conditioning has been limited due to a faulty RF window, which separates vacuum in the waveguide and in the linac. In the sections below different subsystems will be described in detail.

RF PHOTO-INJECTOR

Figure 2 shows the new RF photo-injector system (build by RadiaBeam [4]). It includes the following major components: RF photo-injector, solenoid, waveguide coupler for both forward and reflected RF power signals, RF probe which allows to measure the field amplitude inside the first half-cell of the RF photo-injector and an alignment stand for the RF photo-injector. The solenoid is also installed on top of the remotely controlled KIT alignment stand, which provides additional flexibility in electron beam alignment. The RF photo-injector has 1.5 cells. The cooling system was upgraded. A separate temperature control unit is providing cooling for the RF photo-injector which allows to stabilize the temperature down to 0.3 K. The cathode is removable from the backside of the RF photo-injector, but this would require opening the vacuum volume and after that RF conditioning would be required. Laser injection is on-axis via a metal mirror installed in vacuum along the diagnostic section after the solenoid.

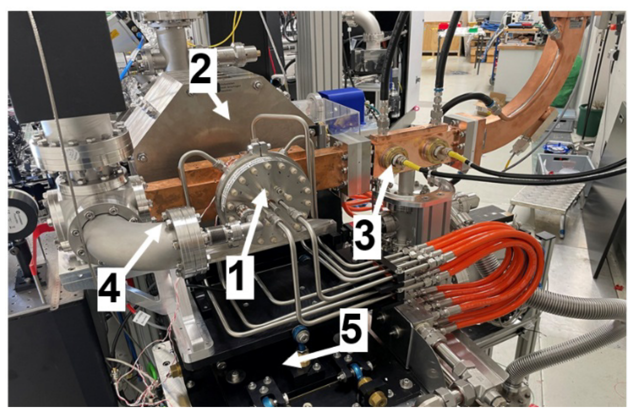

Figure 2: Layout of the new RF photo-injector: 1 – RF photo-injector, 2 – solenoid, 3 – waveguide with the directional coupler for forward and reflected RF power, 4 – RF probe (not seen directly on the picture), 5 – alignment stand for the RF photo-injector.

The envelope of the input RF pulse (Fig. 3a) and a pulse from the RF probe (cannot be seen directly in Fig .2) located on the opposite side of the input waveguide of the RF photo-injector's first half cell is shown in Fig. 3b. The input RF pulse length is 2.3 µsec.

After RF conditioning the following electron beam parameters have been achieved in experimental studies (using diagnostic at the low energy section, between RF photo-injector and linac) (Table 1): electron beam energy 6.0 MeV with 9.3 MW input RF power and 2.3 µsec RF

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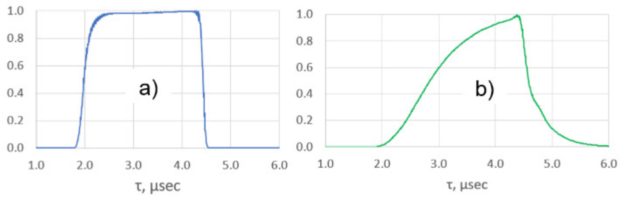

Figure 3: RF pulse from the directional coupler connected to the RF photo-injector, a – input RF pulse, b – pulse from the RF probe.

pulse length, charge 500 pC, with repetition rate of 50 Hz. Parameters of the K100 RF unit are shown in Table 2.

The stability of the electron beam was measured at the low-energy section before the linac and the results are shown in Fig. 4. As one can see an improvement of 10 times in horizontal position and stability was achieved with the RF system upgrade. This improvement allowed experiments with the Compact Transverse Deflecting system described in [1], which has only 20 µm opening in the split ring resonator gap.

Table 1: Beam parameters achieved in KIT experimental studies for the new RF photo-injector from RadiaBeam (using diagnostic at the FLUTE low energy section).

Parameter	Value	Unit
Input RF power	9.3	MW
Frequency	2.997	GHz
Output energy	6.0	MeV
Repetition rate	50	Hz
Bunch charge	500	pC
Peak cathode field	120	MV/m

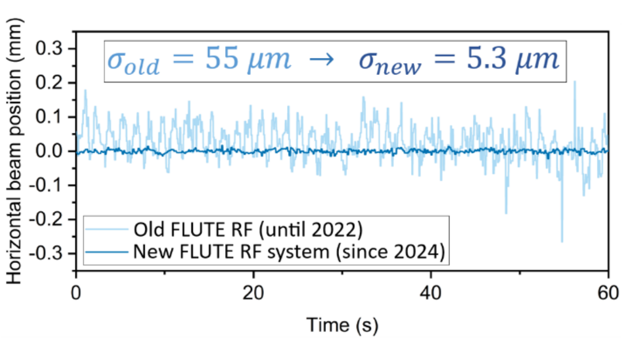

Figure 4: Comparison of the electron beam horizontal position stability for the old RF system [5] and the new RF system.

RF LINAC

The linac is an S-band (2.997 GHz) RF structure, 5.2 m in length that allows to achieve a gain of 80-85 MeV with a RF power of 37 MW and an RF pulse length of 4-4.5 µsec. The linac was built by Research Instruments [6]. Water cooling for the linac is provided by a separate temperature control unit, in order to achieve high temperature stability. The waveguide that allows RF power propagation from the klystron (of K300 RF unit) to the linac is fully vacuum.

Before the RF-upgrade the linac and the RF photo-injector were driven by the same klystron. New RF system utilizes two separate RF units (modulator and klystron) which allows higher RF power for the linac. A comparison of the parameters of the K100 and the K300 RF unit is shown in Table 2. During the commission a fault in an RF window was discovered. This limits, now, the available RF power to approximately 22 MW until the planned replacement later this year.

Table 2: Parameters of the K100 and K300 RF Units

Parameter	K100	K300	Unit
RF power	10.6	36.8	MW
Frequency	2.997		GHz
Output voltage	177	285	kV
Output current	135	315	A
RF pulse length (flat-top)	4.5		µsec
Repetition rate	50		Hz
Pulse to pulse voltage stability	18	20	ppm

ENERGY MEASUREMENTS AFTER THE LINAC

In Fig. 4 and Fig. 5 one can see the overall scheme of FLUTE. After the RF photo-injector a diagnostic section allows to measure electron beam parameters. After the linac, there is a second diagnostic section that allows to measure electron beam parameters after the acceleration in the linac. In order to measure the electron beam energy after the linac, the first two dipoles of the chicane were used together with the screen and Beam Position Monitors (BPM). At first the beam was aligned with the axis of the chicane using a BPM before the first dipole and a BPM after the second dipole. Then after this, the second and third dipoles were moved stepwise off the axis while the magnetic field in all dipoles was increased stepwise in order to keep the beam in the centre of the section between the second and the third dipole. The following formular was used to calculate the electron beam energy:

$$E = \frac{L*q*c*B}{sin(a)} \tag{1}$$

Where L is the length of the first dipole, q – electron charge, c – speed of light, B – magnetic field of the dipole and a – deflection angle between the first and the second dipole.

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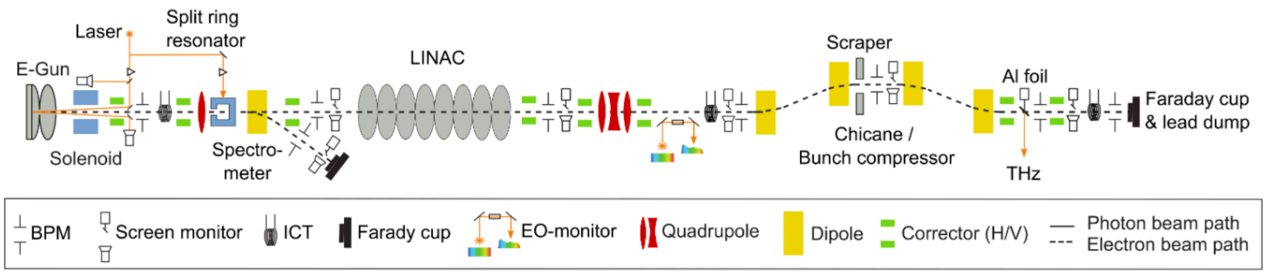

Figure 5: Layout of the FLUTE linac-based accelerator test facility showing the different elements schematically (not to scale). The electron source and a first diagnostics section are followed by the copper linac module followed by the diagnostics section II. Subsequently, the chicane mainly consisting of four dipole magnets allows the tuning of the bunch compression. Then there is the diagnostics section III including the THz generation unit. At the end, the bunch is absorbed in a Faraday cup.

The comparison of the experimental and simulation results with ASTRA code is shown in Fig. 6. The energy that was achieved is limited to 55.7 MeV due to the faulty RF window which separates the vacuum in the waveguide that leads to the linac and the vacuum in the linac. It will be replaced in the middle of 2025 which will allow to increase the energy of the electron beam.

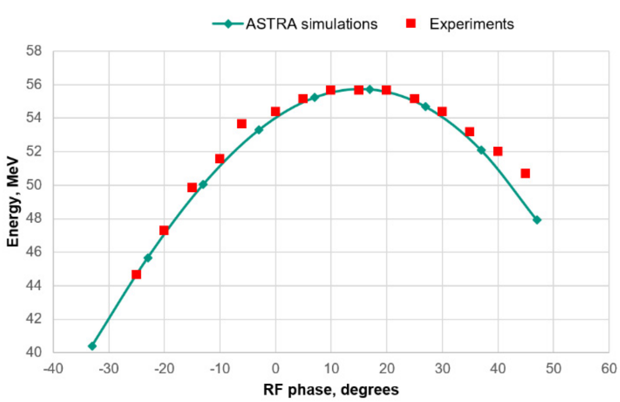

Figure 6: Comparison of the experimental (red squares) and simulation results (green diamonds and a line).

CONCLUSION

The new RF system resulted in 10 times improvement in electron beam stability which enabled experiments with Compact Transverse Deflecting system, much better accuracy for medical irradiation experiments and will improve injection into cSTART. Also, the new RF system allows operation with higher energy (up to 90 MeV) and higher repetition rate (up to 50 Hz).

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