NEW HIGH-STABILITY RF SYSTEM FOR THE FLUTE LINEAR ACCELERATOR

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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 for the generation of strong ultra-short THz pulses for photon science. Also, it will be used as an injector for the 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 photoinjector 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 implemented. In this contribution an RF system design and the status of the RF photoinjector, linac and bunch compressor commissioning will be reported.

INTRODUCTION

Experimental studies of the Compact Transverse Deflecting System (CTDS) [1–3], investigations of coherent THz radiation [4], medical irradiation experiments [5], and injection into cSTART [6] require a highly stable electron beam. To achieve the required beam stability, a new RF system was designed, constructed, and commissioned.

The new RF system consists of an RF photoinjector powered by a K100 RF unit (Scandinova) equipped with a 10 MW S-band klystron (Canon). The RF photoinjector (RadiaBeam) can accelerate electrons up to 6 MeV. After passing through the first diagnostic section, the electron beam is further accelerated in a 5.3 m long S-band linac (Research Instruments) powered by a K300 RF unit (Scandinova) with a 37 MW S-band klystron (Canon).

Downstream of the linac, the beam propagates through a second diagnostic section and subsequently enters a magnetic bunch compressor consisting of four dipole magnets (Danfysik). A third diagnostic section is located after the bunch compressor, followed by a beam dump at the end of the beamline, where the electron beam is safely decelerated and absorbed.

In the following sections different subsystems will be described in detail.

RF PHOTOINJECTOR AND LOW ENERGY SECTION

Fig. 1 shows the new RF photoinjector system (built by RadiaBeam). It includes the following major components: RF photoinjector, 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 photoinjector, and an alignment stand for the RF photoinjector. The solenoid is also installed on top of the remotely controlled KIT alignment stand, which provides additional flexibility in electron beam alignment. The RF photoinjector has 1.5 cells. The cooling system was upgraded. A separate temperature control unit is providing cooling for the RF photoinjector which allows to stabilize the temperature deviation to 0.3 K. The cathode is removable from the backside of the RF photoinjector, but this would require opening the vacuum volume and after that RF conditioning would be required. Downstream of the RF photo-injector, the laser is injected on-axis using a metal mirror installed in vacuum in the diagnostics section.

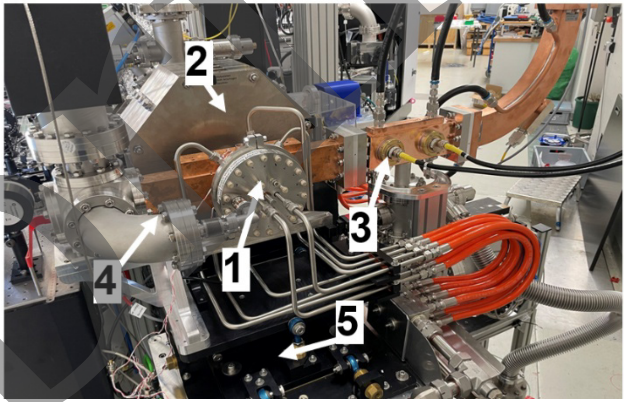

Figure 1: Layout of the new RF photoinjector system. 1 – RF photoinjector, 2 – solenoid, 3 – waveguide section with a directional coupler for monitoring forward and reflected RF power, 4 – RF probe (not directly visible in the figure), 5 – motorized alignment stands for the RF photoinjector.

Fig. 2 shows the waveguide system designed to transmit RF power from the 10 MW klystron of the K100 RF unit to the RF photoinjector while an RF circulator is protecting the klystron from reflected RF power originating from the cavity. Only the short waveguide section containing the circulator is filled with SF_6 gas in order to avoid arcs, whereas the remaining waveguide system designed by KIT and manufactured by Spinner is operated under vacuum at pressures in the low 10^{-9} mbar range. The waveguide system is water-cooled using a dedicated chiller installed in the basement of the experimental hall.

Experimental studies at FLUTE were performed over a wide range of bunch charges, from 70 fC up to 800 pC. Figure 3 shows the dependence of the emitted electron bunch charge on the laser pulse energy. From this measurement, the photocathode quantum efficiency was determined to be 9.7×10^{-5}. For bunch charges above 500 pC, a longer laser pulse and a larger laser spot size on the cathode

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were used, allowing bunch charges of up to 800 pC to be achieved (see Table 1).

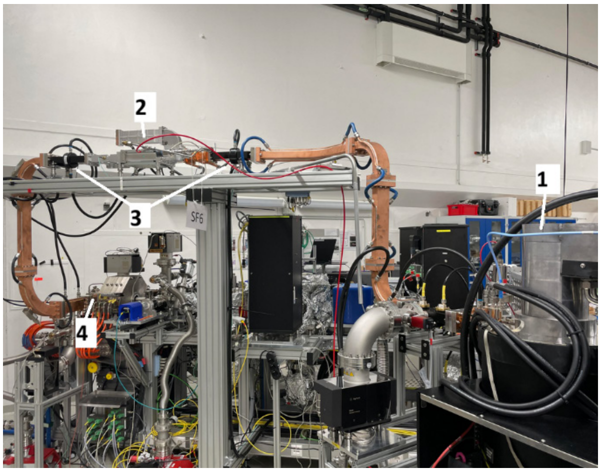

Figure 2: Waveguide system from 10 MW klystron to the RF photoinjector. 1 – 10 MW klystron, 2 – circulator, 3 – RF windows separating SF6 gas and vacuum, 4 – RF photoinjector.

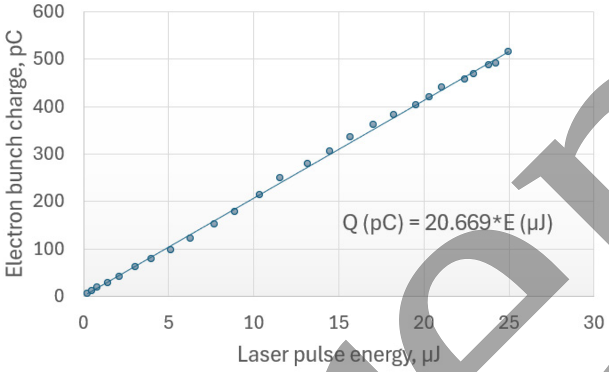

Figure 3: Electron bunch charge versus laser pulse energy.

Table 1: RF photoinjector parameters

Parameter	Value	Unit
Input RF power	10	MW
Energy	6	MeV
Bunch charge	0.07- 800	pC
Peak cathode field	120	MV/m
Maximum repetition rate	50	Hz
Operating frequency	2.998	GHz

The electron beam stability was evaluated in the low-energy section upstream of the linac, and the results are presented in Fig. 4. The measurements demonstrate an approximately tenfold improvement in both the horizontal beam position stability and beam jitter following the RF system upgrade. This substantial enhancement enabled operation of the Compact Transverse Deflecting System described in [1], which features a split-ring resonator gap aperture of only 20 μm.

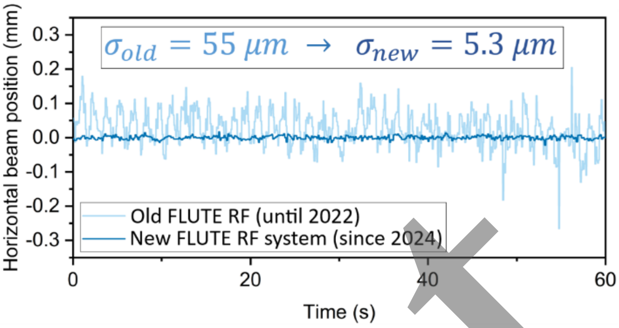

Figure 4: Comparison of the electron beam horizontal position stability for the old RF system [7] and the new RF system presented in this paper.

HIGH ENERGY SECTION

Figure 5 shows the complete FLUTE accelerator installed inside the KIT experimental hall. The linac waveguide system is fully evacuated and does not contain any sections filled with SF_6 gas. The linac was RF-conditioned up to a peak RF power of 21 MW with a pulse length of 3.5 μs and repetition rate of 50 Hz, allowing acceleration of the electron beam up to 56 MeV. Operation at the nominal maximum RF power of 37 MW is expected to provide electron beam energies of up to 90 MeV.

Figure 5: Overview of the FLUTE accelerator: 1 – RF photoinjector, 2 – first diagnostic section, 3 – linac, 4 – quadrupole triplet, 5 – magnetic chicane (bunch compressor consisting of four dipole magnets), 6 – in-air experiment section, 7 – beam dump.

Figure 6 shows an example of the transverse electron beam profile measured at the end of the FLUTE using the in-vacuum screen monitor shown in Fig. 7. The measured beam distribution demonstrates stable beam transport through the accelerator and confirms successful operation of the upgraded RF system at beam energy up to 56 MeV and bunch charges up to 450 pC at the end of FLUTE. The screen system installed in the final diagnostic section enables routine monitoring and optimization of the transverse beam parameters before the beam reaches the in-air experiment area and the beam dump [8].

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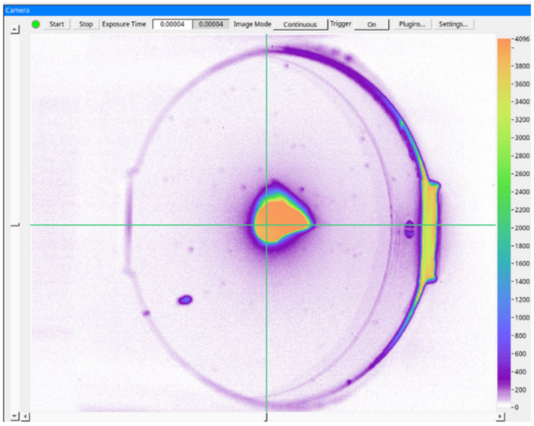

Figure 6: Beam profile with a charge of 450 pC and energy of 56 MeV on the screen after the bunch compressor.

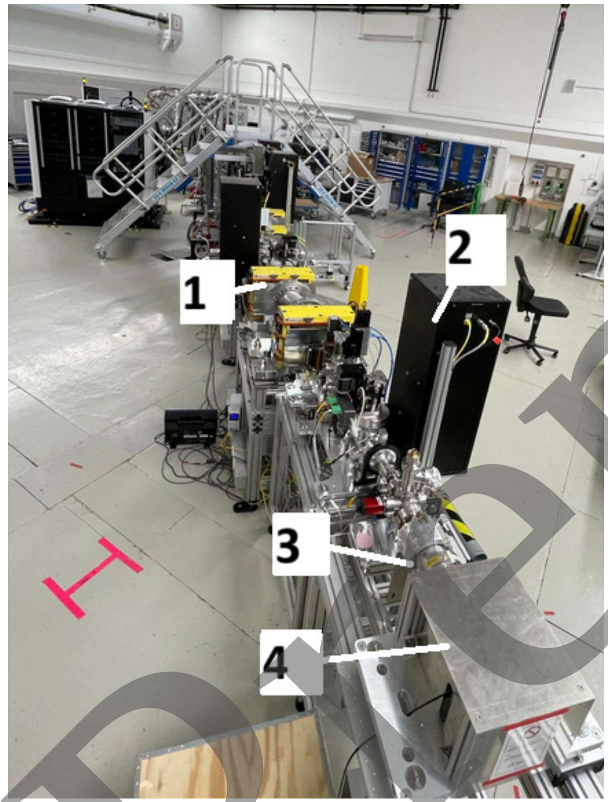

Figure 7: View of the FLUTE end section from the beam dump side. 1 – bunch compressor, 2 – screen monitor, 3 – in-air experiment section, 4 – beam dump.

Figure 7 shows the end section of FLUTE. After the exit of the vacuum tube realized by a metal foil the in-air section [8] provides flexible access for the installation and operation of various experiments, including material or bio-medical irradiation studies.

CONCLUSION

The implementation of the new RF system at FLUTE improved the electron beam stability by approximately one order of magnitude compared to the original one. This enhancement enabled reliable operation of the Compact Transverse Deflecting System and significantly increased the precision of medical irradiation experiments. It will also provide improved conditions for beam injection into the Very Large Acceptance compact Storage Ring (VLA-cSR) for non-equilibrium accelerator research, which is being realized at KIT in the framework of the compact STorage Ring for Accelerator Research and Technology (cSTART) project.

In addition, the upgraded RF system supports operation at repetition rates of up to 50 Hz and will deliver beam energies of up to 90 MeV.

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