DEVELOPMENT AND COMMISSIONING OF THE CUTE-FEL INJECTOR

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Abstract

The injector system for the Compact Ultrafast Terahertz Free Electron Laser (CUTE-FEL) consists of a 1ns, 90 kV pulsed thermionic electron gun, a 476 MHz sub-harmonic prebuncher, and a standing wave, S-band Plane Wave Transformer (PWT) linac capable of accelerating beam to 10 MeV. Beam from this injector will be transported to the entrance of the undulator through a beam transport line, with the required diagnostic elements, that has been designed, developed and commissioned. The control system and the low and high power microwave lines have also been commissioned. In this paper, we discuss salient features of the injector system and results from recent commissioning trials of the injector sub-systems.

INTRODUCTION

The Beam Physics and FEL Laboratory at RRCAT, Indore, is building a Compact Ultrafast TErahertz Free Electron Laser (CUTE-FEL) designed to lase at 80 μm. Figure 1 shows a schematic of the CUTE-FEL setup.

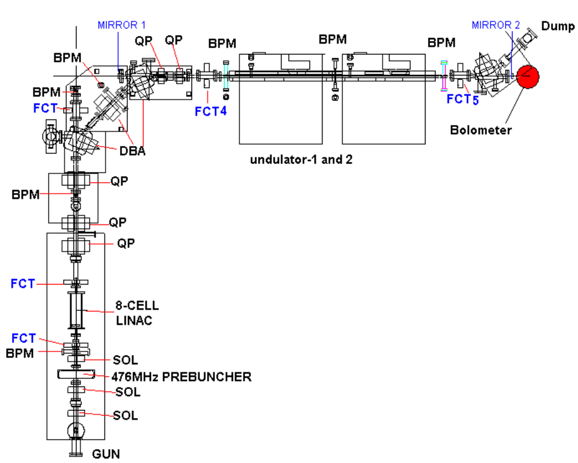

Figure 1: Schematic of the CUTE-FEL beam line.

The injector for the CUTE-FEL is designed to deliver a *10* MeV electron beam with peak current > 20 A, normalized RMS emittance < 30π mm mrad and a RMS energy spread dE/E < 0.5% [1]. To minimize beam loading in the accelerating structure, the pulse structure chosen has micro-pulses of 10 ps FWHM with a spacing of 27.3 ns for a duration of 10 μs at 1-10 Hz. The micro-pulse spacing of 27.3 ns corresponds to the round-trip time of optical pulses in the 4.1 m long optical cavity of the FEL.

In the following sections, we discuss some salient features of the injector system and beam transport line of the CUTE-FEL, followed by a discussion of results obtained from recent commissioning trials of these systems. We also discuss initial results obtained from preliminary experiments on transmission of beam through the undulator generating terahertz undulator radiation.

INJECTOR SYSTEM

The CUTE-FEL injector source is a 90 keV, pulsed thermionic electron gun capable of delivering 1 nC charge in 1 ns FWHM pulses at a repetition rate of 36.615 MHz (corresponding to a pulse spacing of 27.3 ns) for a macro-pulse duration of 10 μs. This electron gun, procured from CCR, Inc., U.S.A., has been installed in the CUTE-FEL beam-line and is operated regularly at rated currents. Figures 2 shows the 1 ns current pulse measured during tests at CCR.

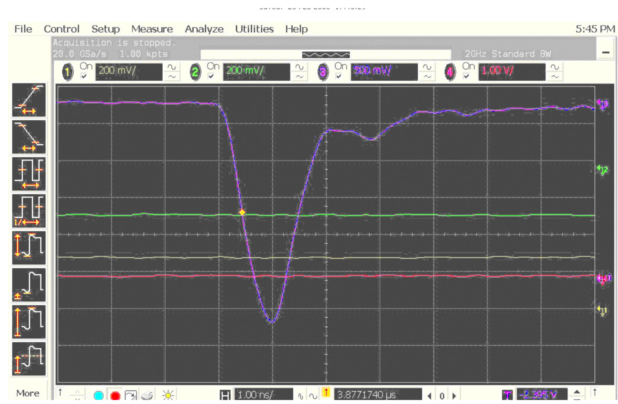

Figure 2: Measured current micro-pulse

The pre-buncher is a re-entrant, Standing Wave cavity made of AISI Stainless Steel (SS) 304L. Two tuning ports have been provided to tune the cavity to its design frequency of 476 MHz. The pre-buncher is designed to bunch the 1 ns beam from the electron gun into 50 – 80 ps bunches consuming around 20 kW peak RF power. The SS pre-buncher structure has been developed and characterized at low powers before being assembled in the CUTE-FEL beam-line. Procurement of a 50 kW peak power source at 476 MHz to power the pre-buncher is in an advanced stage. Figure 3 shows the prebuncher structure during tuning experiments at low RF powers (cold-tests).

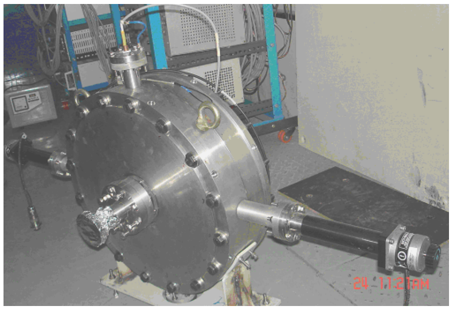

Figure 3: Pre-buncher structure

S-band PWT linac structures with 4-cells and 8-cells have been developed. The 4-cell PWT structure is proposed to be used as a buncher and pre-accelerator, while the 8-cell PWT structure will accelerate beam to the final required energy before being transported to the undulator through the beam transport line. Both the structures have been characterized at low (cold-tests) as well as high RF powers [2]. The 4-cell structure has been conditioned and used in acceleration trials as discussed in greater detail in the next section. Conditioning of the 8-cell PWT linac structure is currently underway and some initial acceleration trials with a 90 keV beam are being done in parallel. Figure 4 shows the disk array of the 8-cell PWT linac structure before assembly, and the final 8-cell structure during cold-tests.

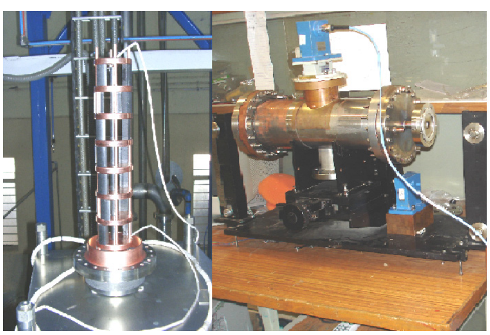

Figure 4: Disk-array of 8-cell PWT linac structure after brazing, and the assembled 8-cell structure.

BEAM TRANSPORT LINE

A schematic of the CUTE-FEL beam transport line is shown in Fig. 1. A 90 keV electron beam from the gun is transported by a pair of solenoids up to the pre-buncher. Beam from the pre-buncher is compressed and transported through a third solenoid up to the linac entrance. Two rotatable steerers are provided for on-line beam steering on to the axis of the linac. The transport line for the accelerated beam comprises of steerers and a triplet of quadrupoles after which the beam is bent into the optical cavity of the FEL through a double bend achromat (DBA). Before entering into the undulator, the beam is transported through a pair of thin quadrupoles and a pair each of steerers for the horizontal and vertical directions. The drift space between the second dipole of the DBA and the undulator entrance is less than 0.5m. Thin combined function quadrupole-cum-steerers of axial size 10cm and a double steerer of axial length 7.5cm have been developed for use in this section [3]. Twiss parameters of the flat beam required at the undulator entrance have been obtained from FEL simulations using the code GINGER [4], and design of the beam transport (see Fig.1) to achieve this has been done using the code TRANSPORT [5]. The beam line from the undulator to the extraction dipole and dump has also been simulated using TRANSPORT. Beam parameters at the undulator exit, simulated by a series of small dipoles, were matched to those expected from free drift in horizontal and matched beam size in vertical. For measurement of beam current, fast current transformers (FCT) have been installed before and after the linac, at the end of the straight section from the gun to the first dipole, and at the undulator entrance and exit. For beam shape/size measurement, a pair of beam profile monitors (BPM) has been installed before and after the linac, three BPMs have been installed with the DBA, and three more at the entrance, middle and exit of the undulator vacuum pipe [3]. By tuning elements of the beam transport line, a flat beam has been transported to the entrance of the undulator. The designed undulator gap for a 10 MeV beam is 35mm.

COMMISSIONING EXPERIMENTS

The CUTE-FEL beam-line has been pumped down to ≤ 1 x 10^{-7} mbar, with pressure in the gun and the accelerating structures being in the good 10^{-8} mbar region. Low and high power microwave lines have been commissioned with the high power line capable of delivering up to 8 MW at 2856 MHz. A control system has been developed for remote operation and monitoring of all sub-systems using a LABVIEW GUI.

Since procurement of the RF power source for the pre-buncher is underway, commissioning experiments have been started with the pre-buncher in the CUTE-FEL beamline acting as additional drift space. After conditioning for a few days with high RF power, the 4-cell PWT structure has been used to obtain an energy gain of 4.2 MeV in acceleration trials with a 90 keV beam. This corresponds to an accelerating gradient of ~ 25 MV/m considering a transit time factor of 0.75. Energy analysis of the accelerated beam is done using the DBA. In the same configuration, the 8-cell PWT linac structure has been conditioned up to gradients of 20 MV/m, and an energy gain of 6.4 MeV has been achieved with 3.5 MW of RF power. Figure 5 shows a typical accelerated beam pulse. Forward and reflected RF pulse shapes at the linac are monitored using a Boonton Power Meter (Model 4500A). Figure 6 shows typical forward and reflected wave forms with the small peak in the reflected pulse shape indicating impedance mismatch in the presence of the beam. The reflected pulse shapes have also been used to obtain information about RF properties of the accelerating structures, as discussed in Ref. [6].

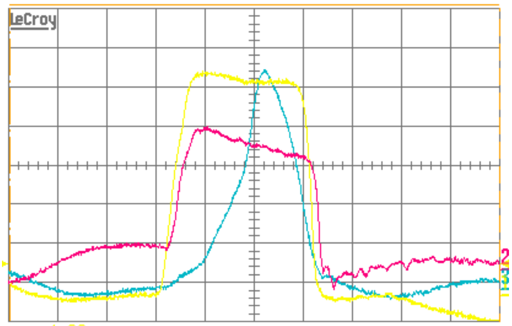

Figure 5: Typical FCT traces showing: Yellow – 90 keV pulse, Red – Accelerated pulse without energy analysis, Blue – Energy Analyzed pulse

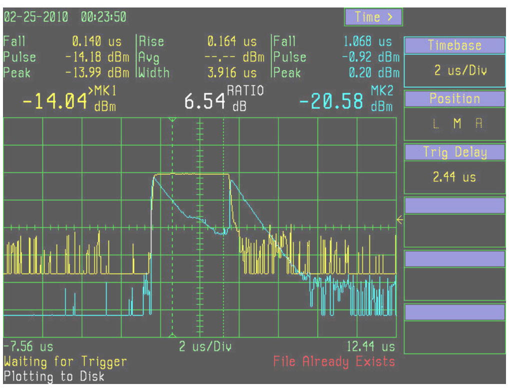

Figure 6: Typical RF pulse shapes at the linac

In another experiment, a 6.4 MeV beam has been successfully transported through the 2.5 m long undulator generating terahertz undulator radiation that was detected using a liquid helium cooled bolometer. Figure 7 shows a typical bolometer signal, which corresponds to a CW average power of ~ 340 pW. Experiments are currently underway to study variation in the bolometer signal with beam current.

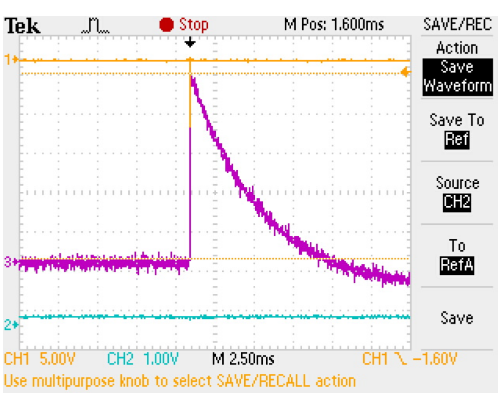

Figure 7: Signal from liquid helium cooled bolometer

CONCLUSION

The injector system for the CUTE-FEL, comprising a thermionic electron gun, a 476 MHz pre-buncher, and 2856 MHz PWT linac has been developed and is in an advanced stage of commissioning. An electron beam of 6.4 MeV has been transported through the undulator generating spontaneous radiation which has been detected using a LHe cooled bolometer. Fine tuning of beam parameters is currently underway.

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