TERAHERTZ RADIATION FROM AN UNDULATOR BASED FEL IN INDIA

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Abstract

The Compact Ultrafast TErahertz Free Electron Laser (CUTE-FEL) is the first THz FEL under development in India. As a first step in its commissioning, a 6 MeV electron beam was transmitted through the undulator, and spontaneous terahertz radiation was detected using a liquid helium cooled bolometer. A brief summary of the various indigenous sub-systems of the FEL and description of experiments performed in four stages, culminating in the detection of ~16 mW terahertz power in a 0.2 μs pulse, is presented. Various beam energy settings have been optimized to generate terahertz light in the range of 1 THz to 3 THz.

SYSTEM DESCRIPTION

A schematic of a typical FEL oscillator using an undulator is shown in Fig. 1. The wavelength of radiation emitted by the undulator is given by $\lambda_L = (\lambda_u/2\gamma^2)(1+K^2)$, where K ($=eB_u\lambda_u/2\pi mc$) is the undulator parameter, B_u is the rms undulator magnet field, λ_u is the undulator period and γ is the Lorentz factor of relativistic electron beam. The radiation line width is given as $\Delta\lambda_L/\lambda_L = 1/N_u$, where N_u number of undulator periods. The CUTE FEL is designed to lase at 80 μm using a 10 MeV e^- beam with peak current ≥ 20 A for a pulse duration of 7-10 μs, normalized rms transverse emittance ≤ 30 mm-mrad and energy spread be ≤ 0.5% [1].

The subsystems of the electron beam injector used in CUTE FEL are described as below.

Thermioninc Electron Gun

It provides a 90 keV, 1 A peak, 1ns FWHM e^- beam pulses at 36.62 MHz. The e^- beam has ~4 mm rms beam radius at waist, ~5 mm mrad normalized rms transverse emittance and <1% energy spread. This gun was bought from Calabazas Creek Research Inc., USA.

Prebuncher

It is an indigenously developed re-entrant type rf cavity resonant at 476 MHz (6^{th} subharmonic of 2856 MHz). It provides velocity bunching of 1 ns long pulses to ~15 ps FWHM and introduces energy spread of ± 28 keV.

Linac

It is indigenously developed water cooled, standing wave, 42 cm long, 8-cell, plane wave transformer (PWT) linac, resonant at 2856 MHz and operated in π mode [2]. The PWT linac disc array and bead pull set up is shown in Fig. 2. This provides an energy gain of ~6.7 MeV at 20 MV/m field gradients and bunching of ~10 ps FWHM.

Transport line

In house developed transport line comprises of two solenoids after gun to focus beam at prebuncher and one solenoid after prebuncher to focus the beam at linac entrance. After the linac, the beam line consists of a quadrupole triplet followed by a double-bend achromat and quadrupole doublet to match the e^- beam parameters to the acceptance of undulator as shown in Fig. 3.

FEL cavity and Undulator

FEL optical cavity is 4.1 m long and houses a 2.5 m long pure permanent magnets undulator (two segments each of 1.25 m long with period of 50 mm and K = 0.8), 2 dipoles, 2 quadrupoles, 8 correctors and 2 concave spherical mirrors in a near-concentric configuration [3]. Undulator was developed indigenously and was mapped using a miniature 3-axis Hall-probe based Teslameter.

Other subsystems

Compact florescent beam profile monitors (BPMs) were developed for e- beam diagnostics. Beam currents were measured using FCTs. A 10 MW RF system was developed to power the PWT linac. Vacuum system and remote control hardware and software for CUTE FEL were also developed.

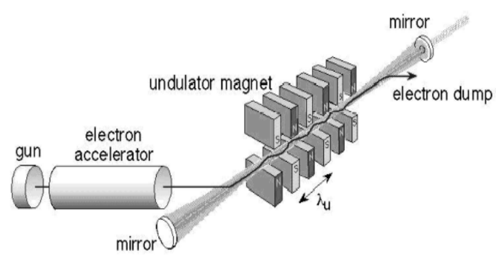

Figure 1: Schematic of a typical FEL Oscillator.

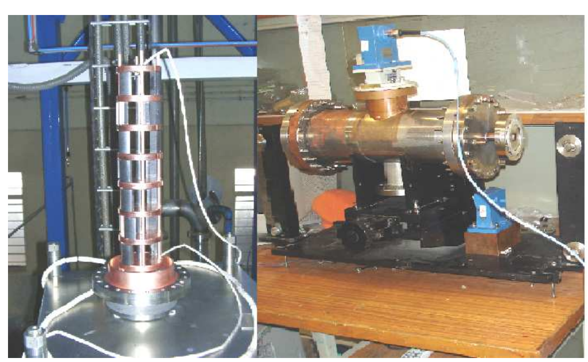

Figure 2: 8-cell PWT linac array and final assembly.

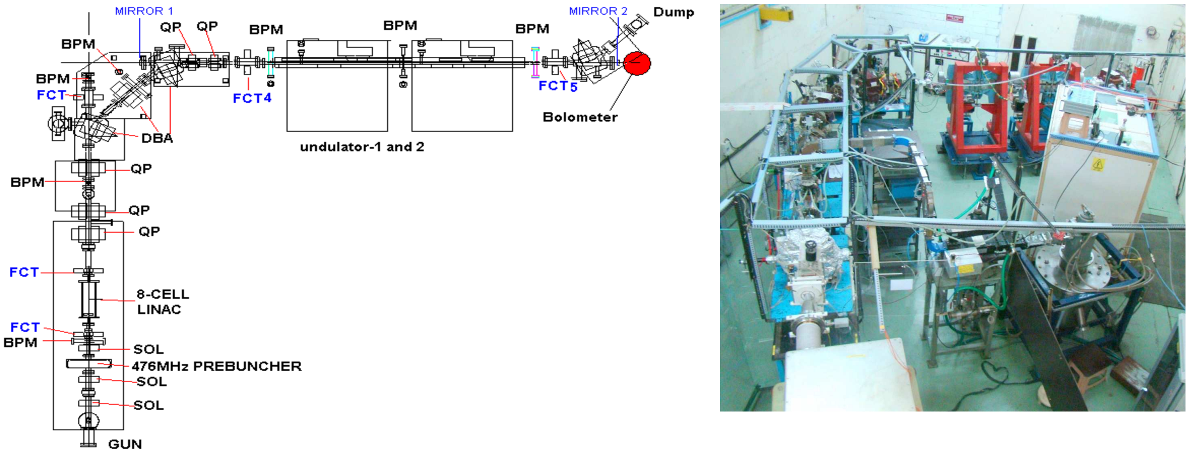

Figure 3: CUTE-FEL beam-line schematic (left) and as assembled in the laboratory (right).

EXPERIMENTS

Commissioning of the CUTE-FEL was done in four stages. In Stage 1, we optimized the transport of the 90 keV e^- beam from the gun to the 4cell and then 8cell linac, without powering the prebuncher cavity. In-situ beam based alignment was done by rotatable steering coils using BPMs and FCT signals. Stage 2 involved rf conditioning of the linac without the electron beam. We monitored the RF Power meter profiles, linac vacuum and dark current spot on BPM mounted before and after the linac. After high power conditioning of the linac, the beam line magnets were tuned to transport a 4-7 MeV, 0.2-0.5 µs long e^- beam, at 1-2 Hz, through the beam line up to the undulator entrance after double bend achromat [4]. The e^- gun grid pulser for 36.62 MHz was under repair. In Stage 3 undulator was installed, in-vacuum mirrors were mounted inside the optical cavity and beam transport line was re-optimized to successfully transmit beam though the undulator. This resulted in the detection of the first signal (650 mV) of THz light by a liquid helium cooled bolometer on 16 April 2010. In Stage 4, beam transport was further optimized and on 4 August 2010, a 0.2 µs long e^- beam pulse of 25 mA, 6 MeV was successfully transmitted though the undulator and 11.2 V signal was detected on the bolometer as shown in Fig. 4. It corresponds to a cw power of 6.5 nW and a macropulse power of ~ 16 mW (average over 0.2 µs) at 1.5 THz radiation. Fig. 5 shows FCT signals of beam currents.

Figure 4: Bolometer signal measuring THz radiation at undulator exit.

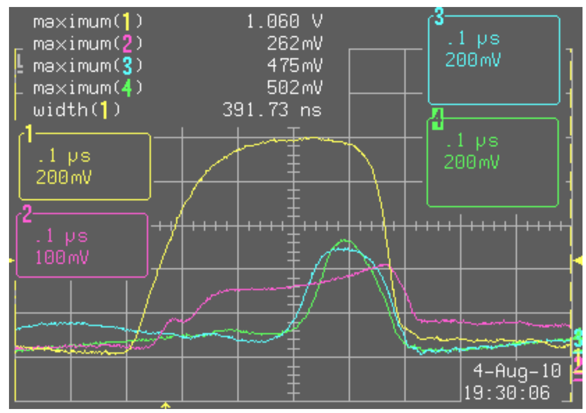

Figure 5: FCT signals: 1A from gun, 262 mA at exit of linac, 32 mA (475 mV) at entrance of undulator and 25 mA (502 mV) at exit of undulator

FUTURE PLANS

Future plan involves installation of electron gun grid pulser (1 ns pulses at 36.62 MHz) which will allow acceleration of longer bunch trains to get enhanced stimulated emission in the CUTE FEL. A diamond window will replace HDPE window to increase the transmission of out-coupled power from FEL cavity. The rf source for the 476MHz prebuncher cavity will be installed and a 12 cell PWT linac will replace the present 8-cell PWT linac to increase the electron beam energy.

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