A.1: First results from an Infra-red Free Electron Laser (IR-FEL) at RRCAT

An Infra-red Free Electron Laser (IR-FEL) designed to lase in the 15 – 50 µm wavelength band has been built at RRCAT, and initial trial operations have been successfully performed to test functioning of different sub-systems and to optimize the transport of an accelerated electron beam through the undulator. When commissioned, this IR-FEL will deliver ~ 10 pico-second long pulses of 1.5 MW peak power output at a repetition rate of 29.75 MHz for a macro-pulse duration of ~ 5 µs with a pulse repetition rate of 1 – 10 Hz.

After installation of the setup inside a 60 m long and 5 m wide shielded area, RF conditioning of the two 12-cell Plane Wave Transformer (PWT) linac structures in its injector system was done with gradually increasing RF pulse width and power level till the desired accelerating field gradient of ~ 20 MV/m was achieved with an RF pulse width of ~ 10 µs. Initial beam trials were done starting with the injection of a 1 µs electron beam into the linac structure for acceleration to ~ 20 MeV. The electron beam transport line was subsequently optimized to transport this beam through the undulator up to the beam dump. During this experiment, the first IR radiation generated from the IR-FEL setup at RRCAT was measured using a liquid Helium cooled bolometer. The electron beam transmission was further optimized, ultimately leading to saturation of the bolometer signal in the high gain regime, which corresponds to an average output power of ~ 4 mW over 1 µs pulses. Figure A.1.1 shows traces of the electron beam obtained using Integrating Current Transformers (ICTs) mounted at different locations along the beam transport line with ICT1 corresponding to the ICT after the electron gun and ICT5 corresponding to the ICT at undulator exit.

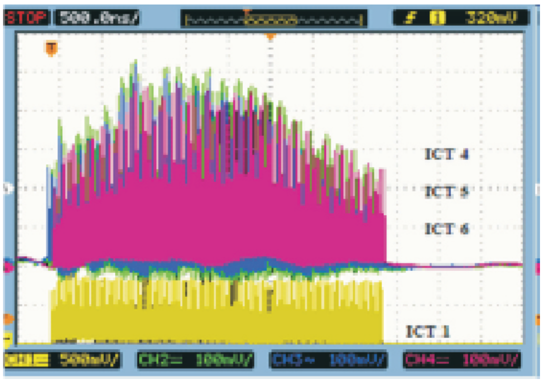

Fig. A.1.1: ICT signals at different locations along the electron beam transport line

In the next set of experiments, the electron beam pulse width was increased to 4 µs and the electron beam transmission was optimized for efficient transport of the accelerated electron beam through the undulator. The IR radiation generated in the process was again measured using a liquid Helium cooled bolometer, whose signal showed saturation in the low gain region. This corresponds to an extrapolated average IR power output of ~ 7 mW over 4 µs. The wavelength of IR radiation generated in these experiments was estimated to be ~ 36 µm based on the beam energy of 19.5 MeV and the undulator settings used in the experiment. Figure A.1.2 shows the trace of the saturated bolometer signal.

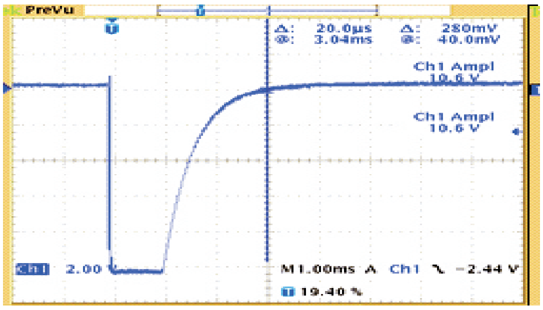

Fig. A.1.2: Bolometer trace showing saturated IR signal

The optical cavity of the IR-FEL was subsequently installed and aligned to ensure that its axis coincides with the undulator axis. During experiments, the electron beam transport line is tuned to ensure that the electron beam path inside the optical cavity coincides with the optical cavity axis, and that the size of the electron beam matches the size of the optical beam as they co-propagate through the undulator for good overlap leading to efficient exchange of energy between the two. Around 5% of the intra-cavity power is out-coupled through a 2 mm hole at the centre of the downstream mirror. Beam transmission experiments were repeated with the optical cavity to verify alignment. The measured out-coupled IR power agrees well with the IR power measurements performed before installation of the downstream mirror, thereby confirming the alignment of the optical cavity with the beam axis. The mirrors of the optical cavity are mounted on precision six-axis hexapods, and the downstream mirror will be moved remotely to change the length of the optical cavity during experiments to study lasing.

Recent measurements of the electron beam parameters in the IR-FEL setup have confirmed achieving of 30 A peak micro-pulse current over short electron beam macro-pulses with 0.5 % RMS energy spread and ~ 45 mm mrad normalized RMS emittance. The RF system of the IR-FEL is presently being tuned to facilitate increase of the electron beam flat-top pulse width to ≥ 6 µs, which is essential for studying build-up of cavity power and coherence. Experiments to study build-up of coherence and lasing are scheduled to begin in the near future after completion of the ongoing RF system up-grade.

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