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Computational Challenges in the Development of THz FELs at National Synchrotron Radiation Research Center

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Intense THz radiation has found critical applications in the study of quantum and semiconductor materials, as well as in the manipulation of electron beams. In response to this, a THz Free Electron Laser (FEL) facility has been developed at NSRRC, designed to deliver high peak power for user operations. This facility generates coherent radiation within the 0.6 to 1.4 THz frequency range. The radiation is produced by passing a sub-picosecond electron beam through a planar undulator with a 10-cm period length, where the undulator gap is adjustable. The short-bunch electron beam itself is produced by the NSRRC photoinjector, with a booster linac operating near the zero-crossing phase to achieve RF bunch compression. This method has successfully compressed the electron bunch to a minimum duration of 240 fs at a beam energy of 25 MeV. However, the bunch form factor's limited frequency range restricts the highest achievable superradiant THz frequency to around 1-2 THz.

To overcome this limitation, a double dogleg magnetic bunch compressor is being considered to further reduce the bunch duration, thereby extending the radiation to even higher frequencies. The output characteristics of the superradiant undulator emission are highly sensitive to the bunch form factor, which is closely tied to the longitudinal electron distribution. Since space charge effect in the photoinjector is significant, the 3D space-charge tracking code – IMPACT has been employed to simulate the RF bunch compression process and study beam dynamics in the double dogleg magnetic bunch compressor. These simulations have allowed for accurate determination of electron distributions at the entrance of undulator, which are then used in the broadband FEL code – PUFFIN to calculate the radiation output properties for the THz beamline design.

Additionally, the feasibility of developing a THz Self-Amplified Spontaneous Emission (SASE) FEL beyond the 3 THz frequency range is under consideration, driven by the same accelerator system. However, a beam dechirper may be required to reduce correlated energy spread after bunch compression. To study the effects of short-range wakefields produced by the dielectric-lined waveguide dechirper or other advanced designs on multi-particle dynamics within the accelerator, reliable wake functions have been deduced from CST-calculated wake potentials via deconvolution. This report will highlight the computational challenges involved in the development of THz FELs at NSRRC.

Primary authors: Dr CHIANG, Wei-Yuen (National Synchrotron Radiation Research Center); TENG, ShanYou (National Synchrotron Radiation Research Center / National Central University); Dr LAU, Wai-Keung (National Synchrotron Radiation Research Center)

Co-authors: QIANG, Ji (Lawrence Berkeley National Laboratory); Prof. CHEN, Shih-Hung (National Central Univeristy)

Presenter: Dr CHIANG, Wei-Yuen (National Synchrotron Radiation Research Center)

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