Accelerator-based tunable THz source for pump-and-probe experiments at the European X-ray Free-Electron Laser facility

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Abstract— There is a high demand for intense THz sources since “many excitation mechanisms of matter resonate in the terahertz regime” especially for condensed matters. “Accelerator-based THz sources provide the wide tunability together with high intensity and repetition rates beyond 100 kHz, that will enable broad application at the European XFEL to the most interesting scientific problems in the field” [1]. Supported by European XFEL a proof of principle study is started at the Photo-Injector Test Facility located at DESY in Zeuthen site (PITZ). Since PITZ and European XFEL electron sources are identical the X-ray and THz radiation can be produced with identical bunch train structure so that for every X-ray pulse a corresponding THz pulse can be provided for the pump-and-probe experiments.

I. INTRODUCTION

DESY is one of the pioneers of photon science in the world especially in the field of Free-Electron Laser science. FLASH and European XFEL complementary covers soft and hard X-rays for observing the material in the nanoscale and sub-nanoscale. The pump-and-probe mechanism is the heart of most experiments in both facilities. In this mechanism, a high energy/short pulse electromagnetic wave (pump pulse) excites the sample to a new state and a femto-second X-ray pulse (probe pulse) observes its dynamics [1]. Existing laser-based THz sources can provide high repetition rates pump pulses but only at very low pulse energy. Also the THz radiation frequency is usually below 3 THz with limited tunability. It is possible to avoid this limitation by using accelerator-undulator-based THz sources. They can reach above 3 THz radiation frequency and are better tunable (Fig. 1).

Fig. 1. Comparison between Laser-based and accelerator-based THz sourced for pump-and-probe experiments. 1-4: Optical rectification 5: Photoconductive antenna 6: Two-color laser filamentation 7: Coherent transition radiation (LCLS/FACET) [4] 8: Undulator radiation (FLASH) 9: Undulator Radiation (TELBE) [5]. The star shows our project goal.

FLASH has a THz beamline for the pump-and-probe experiments. It is an afterburner facility which sends the electron beam at the end of FLASH inside an undulator to produce an intense THz beam. But still the European XFEL users suffer the lack of enough powerful high repetition rate THz sources [1]. Our goal is to design an accelerator-based tunable THz source which can be installed next to the European XFEL experimental hall. And also to do proof-of-principle studies at PITZ using an existing accelerator tunnel extension and LCLS-I undulators on loan from SLAC [2]. PITZ operation started in 2001 and its aim was to provide the best quality injector for FLASH and European XFEL and to carry out several R&D projects in the field of accelerator physics. PITZ, with identical electron source to European XFEL, is considering to use a low energy beam (16-22 MeV) to produce THz radiation for the proof-of-principle studies. Using two identical electron sources to produce X-ray and THz radiations, allows pump-and-probe experiments for every pulse in the pulse train of European XFEL. For the proof-of-principle study, a train of bunches with 4nC, 200A peak current and 16-22 MeV is planned to be sent to a LCLS-I undulator to produce THz radiation by means of self-amplified spontaneous emission (SASE) process. The LCLS-I undulator is selected because of its availability and it should allow to perform the proof-of-principle studies, although preliminary numerical studies using an APPLE-II undulator have shown higher pulse energies of about 2mJ at 3 THz radiation frequency (100μm) [3]. PITZ is planned to create the flexibility to also work in the super-radiant regime (CEP-stable) at lower charges by using a magnetic bunch compressor and seeding mechanisms. In this paper the project and its progress will be summarized. It also includes a physics review of THz radiation inside the undulator beam pipe, the radiation protection of the undulator permanent magnets as well as, super-radiant and seeding options using magnetic bunch compressor.

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