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BEAM LINE DESIGN AND INSTRUMENTATION FOR THz@PITZ – THE PROOF-OF-PRINCIPLE EXPERIMENT ON A THz SASE FEL AT THE PITZ FACILITY

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Abstract

In order to allow THz pump–X-ray probe experiments at full bunch repetition rate for users at the European XFEL, the Photo Injector Test Facility at DESY in Zeuthen (PITZ) is building a prototype of an accelerator-based THz source. The goal is to generate THz SASE FEL radiation with a mJ energy level per pulse using an LCLS-I undulator driven by the electron beam from the PITZ linac. Therefore, the existing PITZ beam line is upgraded and extended into a tunnel annex downstream of the existing accelerator tunnel.

The beam line upgrade in the PITZ tunnel consists of three quadrupole magnets, a bunch compressor, a collimation system and a beam dump followed by the connection to the second tunnel. In the second tunnel a dipole magnet allows to serve two beam lines, one of them is the THz@PITZ beam line. It consists of one LCLS-I undulator for the production of the THz radiation, a quadrupole triplet in front of it for matching the beam parameters for the FEL process, and a quadrupole doublet for the electron beam transport to the beam dump behind it. For the electron beam diagnostic six new screen stations are built, three of them also allow for the observation of the THz radiation for measurements like bunch compression, pulse energy or spatial and transverse distribution. Additionally, five BPMs and a new BLM system for machine protection and FEL gain curve measurement will be installed. The progress of the beam line installation and the instrumentation will be presented.

INTRODUCTION

The European XFEL plans to expand the wavelength range for pump-probe experiments into the THz-regime for probing the samples. Therefore different options for the THz generation were studied [1, 2]. For the accelerator based source a proof-of-principle experiment is being prepared at the Photo Injector Test Facility at DESY in Zeuthen (PITZ). Here the THz radiation is produced using a Self-Amplified Spontaneous Emission (SASE) FEL in an LCLS-I undulator [3], driven by the electron bunches from the PITZ accelerator. Start-to-End simulations for this setup, i.e. beam energies of 16 to 22 MeV/c and a peak current of 200 A (i.e. 4 nC bunch charge), yielded a THz pulse energy of about 0.5 mJ at a wavelength of 100 µm [4, 5].

A schematic overview of the current PITZ beam line as well as the planned extension (red dashed box), is shown in the top part of Fig. 1. The electrons are generated in the gun, accelerated up to ≈ 7 MeV/c, before further acceleration by the booster to the final energy of ≈ 24 MeV/c takes place. The different diagnostic devices, e.g. HEDA1, EMSY and TDS, allow for a measurement of the six dimensional phase space of the electron beam and therefore to characterize the photo-injector performance.

BEAM LINE EXTENSION

For the THz@PITZ project the beam line in the PITZ tunnel has to be modified and also has to be extended into the second tunnel, the tunnel annex. To extend the range of operation modes a bunch compression chicane is added to the beam line in the PITZ tunnel. It is designed to be a multi purpose device, in particular, it will allow to generate THz radiation with lower bunch charges than the planed 4 nC by maintaining the peak current of the electron beam through longitudinal compression [6, 7]. In addition to that, it enables the investigation of seeding methods for the THz generation [8]. Two quadrupole triplets, one in the PITZ tunnel and one in the tunnel annex, are foreseen for the matching of the electron beam into the undulator. Since the undulator chamber is quite narrow (11 mm x 5 mm) the matching is the most crucial part. Additionally, a collimator system reduces the number of halo particles and dark current before the beam enters the tunnel annex. This should reduce the beam loss, due to the chamber size, in the undulator significantly.

The beam line in the tunnel annex consists of a dipole magnet, which can be used as a switchyard to serve a second beam line in the future, the second quadrupole triplet, the undulator, two additional quadrupole magnets and a dipole for the deflection of the beam to the high power beam dump. The beam dump in the straight section will only be used to set up the beam or for moderate average power operations. In total three screen stations for THz diagnostics, one in front of and two behind the undulator, are installed. The first one is used for bunch compression measurements when the bunch compression chicane is used. In addition it can be used for coupling in seeding radiation for future seeding experiments and it will be used to calibrate the positions of the THz mirrors behind the undulator.

The two screen stations behind the undulator are equipped with mirrors to deflect the THz radiation vertically to a viewport where it is coupled out of the vacuum system and guided

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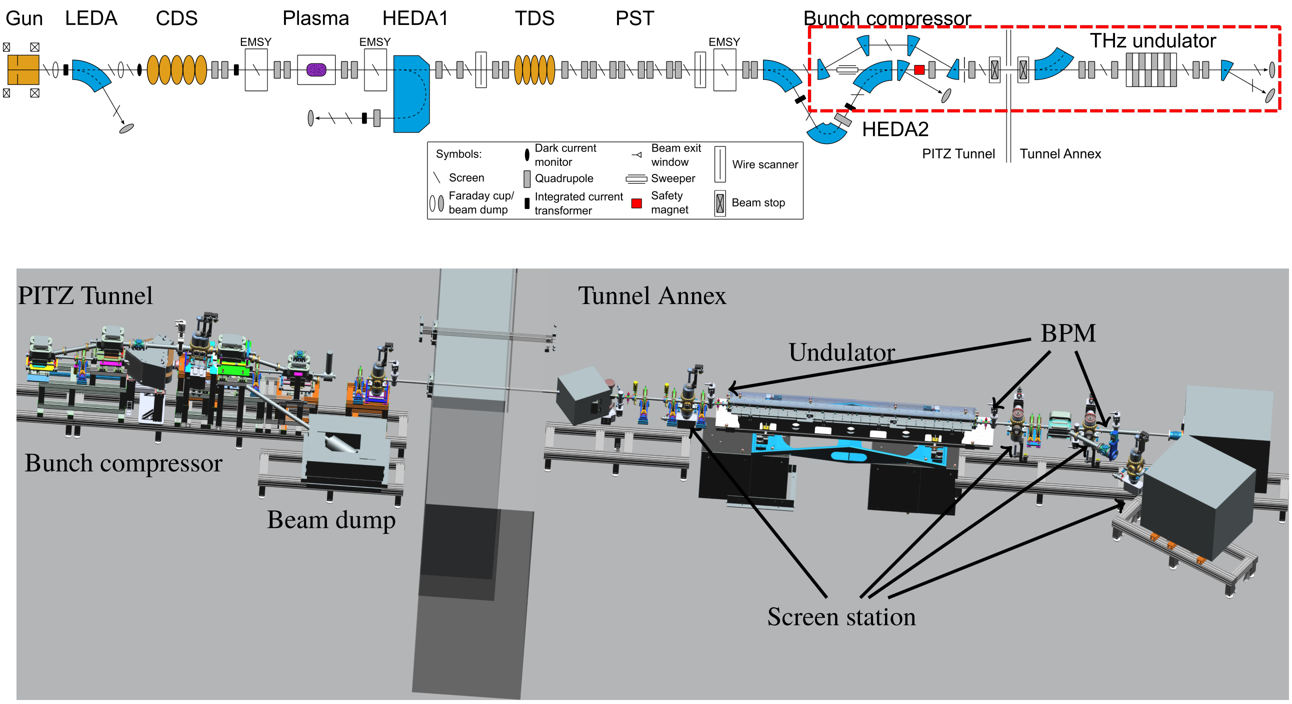

Figure 1: Schematic overview of the complete PITZ beam line (top). The beam line extension for the THz@PITZ project is surrounded by the red dashed box, while the CAD model of the beam line extension is shown in more detail in bottom of the figure.

to the THz diagnostic table. The first mirror has a hole to let the electron beam pass, while a dipole magnet between the two screen stations deflects the electron beam to a beam dump, thus removing the need for a hole in the second mirror. This allows for a higher fraction of the THz radiation to be deflected and analyzed in the THz diagnostic setup. The THz diagnostic setup is used to measure the total pulse energy, the polarization as well as the transverse and spectral distribution with a pyro detector, a Michelson interferometer setup and a THz camera.

In addition to the screen stations five new BPMs will be installed to measure beam position and charge. These are located in the chicane, in front of the wall as well as in front and behind the undulator to ensure a good coverage of the whole beam line. A beam loss monitor system (BLM) based on optical fibers will be used to measure the beam loss along the beam line.

A detailed 3d-model of the planned beam line extension is shown in Fig. 1 (bottom).

Screen Stations

In total six new screen stations have been designed for the beam line extension. They were designed in a modular way to minimize the number of different parts during production and purchasing. All are equipped with the same type of actuator, to allow for a movement of 200 mm, and the vacuum chambers differ only in the beam pipe diameter, depending on their placement in the beam line. This ensures a quicker production of the individual parts as well as less spare parts have to be stocked and also preserves flexibility for future upgrades, like seeding options.

The screen holder was also designed to fulfill the requirements of the different screen stations, e.g. the screen station in the chicane is equipped with a larger screen and a slit while the THz screen stations have two screens and a THz mirror. All screens are mounted perpendicular to the electron beam to avoid depth of field issues while a 45°-mirror behind the screens allows for the observation of the beam with a camera. The cameras have two different lenses, which can be put in the optical path, to enable two different magnification options for each screen. In addition all screen holders have a test target which is used to set up the camera, i.e. to calculate the calibration factor to convert pixels to mm.

In Fig. 2 a CAD model of a screen station is shown. Since it is one of the THz screen stations, it is equipped with two screens and the THz mirror, which is currently shown inserted. In-vacuum roller bearings increase the stiffness of the actuator and should reduce positioning errors. The screen holder has two screens, here a YAG and a second one made from a material with a higher light yield, for low intensity beams (LYSO was used untill now but further material studies are planned to determine the exact material). Due to the side view of this CAD model the screens and the test target can not be seen, instead the 45°-mirror which is used to

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image the screens is visible on the holder. Since it is the first screen station after the undulator, the THz mirror has a hole to let the electron beam pass while deflecting a fraction of the THz radiation upwards through a window and into the THz diagnostic beam line. For the material of the THz windows diamond was chosen to minimize transmission losses.

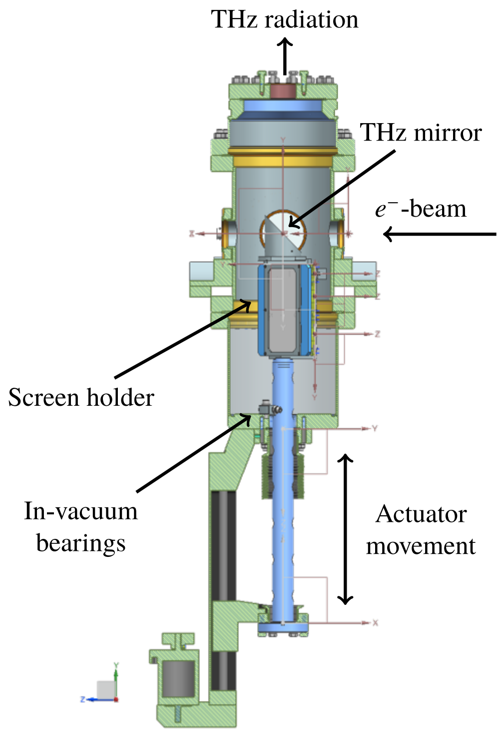

Figure 2: CAD model of a screen station. The screen stations are equipped with two screens, one YAG and one with a material with a higher light yield (tbd), a mirror to view the screen with the camera and in case of this screen station a THz mirror to couple out the THz radiation through a THz viewport (deflection to the top w.r.t. the beam path).

Installation Progress

In order to extend the beam line into the tunnel annex the tunnels are connected by two core holes, one for the beam line and one for alignment purposes. The alignment hole will be closed during operation but can be opened for transfer measurements, if needed. Additionally the preparations of the tunnel annex for the beam line installation included the installation of a crane, infrastructure installation, e.g. power, network and gas distribution, and the personal interlock system.

After this work, the installation of the undulator support structure, two granite blocks to dampen oscillation, was done and the undulator support frame was installed, see Fig. 3. Since there is still some construction work to be done which creates a lot of dust, the installation of the undulator magnet is postponed till this work is finished.

Besides the installation work a lot of components have been already produced, e.g. the vacuum chambers of the bunch compressor chicane, delivered, e.g. the quadrupole and dipole magnets, or are currently under production, like the screen stations. Improvements on the radiation shielding in the PITZ tunnel allow now for an access to the tunnel annex during PITZ operation, which increases the time available for the installation of the beam line.

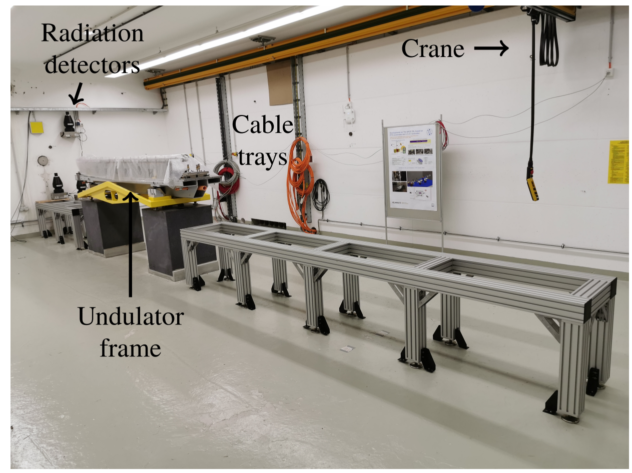

Figure 3: Support structures for the beam line and the undulator installed in tunnel annex. The undulator support frame is mounted on top of two granite block for vibration damping. In the background cable trays as well as other installations, e.g. crane and radiation detectors, can be seen.

CONCLUSION AND OUTLOOK

The design of the beam line extension for the THz@PITZ project is nearly completed and the preparatory work in the tunnel annex (infrastructure) is finished. First parts of the beam line, the undulator and parts of the support structures of the beam line, have been installed while other parts have been purchased or are under production. While the installation progresses additional work on the THz diagnostics as well as the conceptual design report, including beam optics simulations, is carried out.

The last heavy construction work, which creates a lot of dust, is scheduled for the end of May and afterwards the installation of the beam line can continue. We are still aiming to have the first beam in the undulator this year.

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