CALCULATIONS FOR A THz SASE FEL BASED ON THE MEASURED ELECTRON BEAM PARAMETERS AT PITZ

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Abstract

The Photo Injector Test facility at DESY, Zeuthen site (PITZ), develops high brightness electron sources for modern linac-based Free Electron Lasers (FELs). The PITZ accelerator can also be considered as a suitable machine for the development of an IR/THz source prototype for pump-probe experiments at the European XFEL. Calculations of THz radiation by means of a SASE FEL based on the simulated and the measured beam profiles at PITZ for the radiation wavelength of 100 µm were performed by using the GENESIS1.3 code. The results of these simulations are presented and discussed in this paper.

INTRODUCTION

The Photo Injector Test facility at DESY, Zeuthen site (PITZ) has been established to develop, study and optimize high-brightness electron sources for modern linac-based short-wavelength Free-Electron Lasers (FELs) like FLASH [1] and the European XFEL [2].

The concept of generating IR/THz radiation by electron bunches from a "PITZ-like" accelerator for pump and probe experiments at the European XFEL was presented in [3]. PITZ has been considered as an ideal machine for the development of such IR/THz source. Start-to-end (S2E) simulations of the SASE FEL from a PITZ-like accelerator were performed and presented in [4]. An electron beam with 4 nC bunch charges was used for the FEL generation. Experimental optimization and characterization of 4 nC electron beams including time-resolved measurements were done and presented in [5].

In this paper, we present results of beam dynamics simulation using the actual PITZ beamline layout together with the results of electron beam measurements. Then, we performed SASE FEL simulations based on the simulated and the measured beam profiles for a radiation wavelength of 100 µm by using the GENESIS1.3 code. The initial seed for the random number generator used for particle phase fluctuation in the GENESIS1.3 code was scanned in order to simulate the FEL pulse energy fluctuation during the SASE FEL process.

BEAM DYNAMICS SIMULATION

Since works in [4] were studied by using only a PITZ-like beamline layout, the beam dynamics simulations with the actual PITZ layout were re-done. The actual PITZ beamline plus an extension for simulation studies for an IR/THz SASE FEL at the end of the beamline is shown in Fig. 1. The layout consists of a 1.6-cell L-band photocathode RF gun surrounded by main and bucking solenoids, a CDS booster, a TDS cavity, screen stations, quadrupole and dipole magnets and an APPLE-II type undulator which is assumed to be placed at the end of the beamline. Dispersive sections (LEDA, HEDA1 and HEDA2) are used for electron beam momentum and longitudinal phase space (LPS) measurements.

The ASTRA code [6] is used for simulation of the electron beam with 4 nC bunch charge from the cathode to the undulator entrance. Space-charge effects were included in the simulation as well. Machine parameters used in this simulation are shown in Table 1. The RF gun phase was adjusted for the maximum mean momentum and the booster phase was adjusted for the minimum momentum spread. The quadrupole magnets along the beamline were used for beam transport and matching. The simulated beam parameters at the undulator entrance are listed in Table 2.

Table 1: Machine Parameters Used in Beam Dynamics Simulations and Measurements. PC means Photocathode.

Parameter	Sim.	Meas.
PC laser long. pulse shape	Flat-top	Gaussian
PC laser pulse duration (FWHM) [ps]	~20	~11
PC laser diameter on the cathode [mm]	5.0	3.7
Peak E-field in the gun [MV/m]	60.5	60.5
Peak E-field in the booster [MV/m]	9.8	9.8

Table 2: Electron Beam Parameters Resulted from Beam Dynamics Simulation and Measurements

Parameter	Sim.§	Meas.†
Bunch charge [nC]	4.0	4.0
Average momentum [MeV/c]	15.1	15.2
Momentum spread [keV/c]	134.7	50.9
Average slice momentum spread [keV/c]	6.2	28.5
Projected $\varepsilon_{n,x}$[µm]	7.9	7.1
Projected $\varepsilon_{n,y}$[µm]	7.6	11.1
Average slice $\varepsilon_{n,x}$[µm]	3.1	10.9
Average slice $\varepsilon_{n,y}$[µm]	3.1	-
Peak current [A]	195	183
Bunch length [mm]	2.0	3.0

§ The simulated beam parameters at the undulator entrance
† The measured beam parameters at the measurement stations

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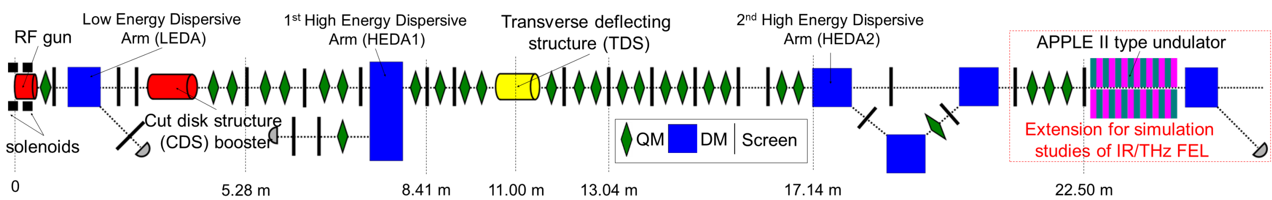

Figure 1: Layout of the actual PITZ beamline plus an extension for an IR/THz FEL for simulation studies. Here QM, DM and screen represent quadrupole magnets, dipole magnets and screen stations for monitoring of beam transverse profiles, respectively. The numbers represent the distance from the photocathode location (z = 0).

BEAM MEASUREMENTS

Machine parameters used for the 4 nC beam measurements are also listed in Table 1. Different from the simulation, a photocathode laser pulse with Gaussian temporal shape was used because this profile was the only one available at that time due to technical reasons. The laser diameter on the cathode was also reduced to 3.7 mm in order to have an acceptable uniform transverse laser profile on the cathode. Similar to the simulation, the RF gun phase was adjusted for the maximum mean momentum measured by LEDA and the booster phase was adjusted for the minimum momentum spread measured by HEDA1.

Some parameters of the 4 nC electron beams which are necessary for SASE FEL calculations were measured including, projected momentum profile, transverse phase space, current profile, slice transverse emittance and slice momentum spread. Details about the measurements of the 4 nC electron beams are presented and discussed in [5]. The measured beam parameters are listed in Table 2 together with the parameters from the beam dynamics simulation. Note that measured beam parameters are parameters at their measurement stations. By transporting the electron beam to the location of the undulator entrance, these parameters may have been changed. However, in this work we assumed that they are parameters at the undulator entrance for comparison of FEL simulation results from both cases.

SASE FEL CALCULATIONS

The GENESIS1.3 code [7] is used for simulations of the SASE FEL radiation. An APPLE-II undulator in helical mode [8] with period length of 40 mm and total length of 5 m (125 periods) is used as the radiator. The simulations were performed for a radiation wavelength of 100 µm using a 15 MeV/c beam. We assumed that the simulated and measured beam parameters in Table 2 are those at the undulator entrance. The Twiss parameters of the beams were assumed to be matched for beam transport along the undulator.

In order to simulate the FEL pulse energy fluctuation during the SASE FEL process, the initial seed for the random number generator used for particle phase fluctuation [9,10] in the GENESIS1.3 code was scanned from 1 to 100. Figure 2 shows results of the simulated FEL pulse energy averaged from the 100 simulations along the undulator axis (black lines). The grey areas are shadows of all plots from the 100 simulations. The blue dot-lines show the fluctuation

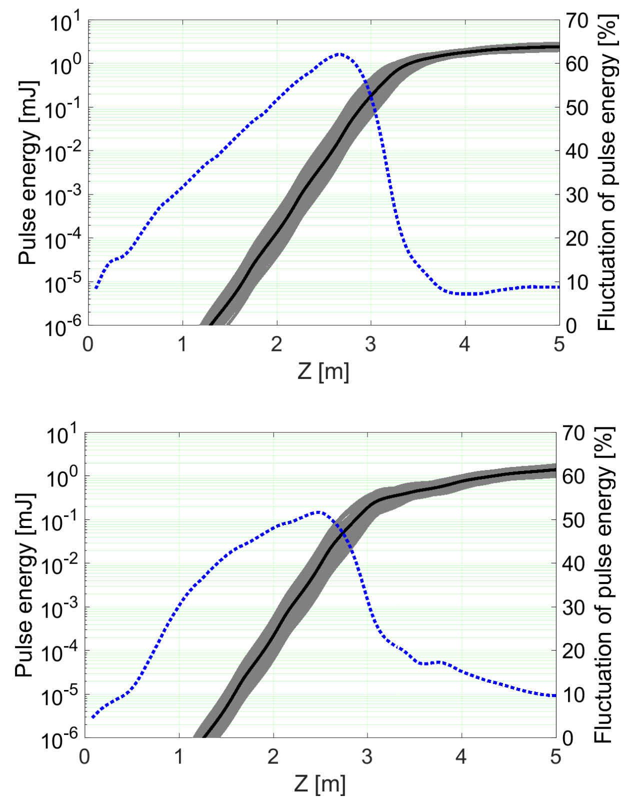

Figure 2: Simulated FEL pulse energy averaged from the 100 simulations along the undulator axis (black lines) based on the simulated (top) and measured (bottom) electron beam parameters. The grey area shows shadows of all plots from the 100 simulations. The blue dot-line shows the fluctuation of the pulse energy along the undulator axis.

of the pulse energy along the undulator axis which is a ratio between standard deviation of the pulse energy and the averaged pulse energy at each position along the undulator. For the case based on the simulated beam parameters, the pulse energy at the undulator axis reaches 2.7 mJ with 8.4% fluctuation.While for the case based on the measured beam parameters, the pulse energy at the undulator axis reaches 1.7 mJ with 10.2% fluctuation.

Figure 3 shows temporal profiles of the radiation pulses averaged from the 100 simulations at the undulator exit (z = 5 m), while the spectrum profiles are shown in Fig. 4. The grey areas in these figures are also shadows of all plots from the 100 simulations. They cover quite big areas which mean

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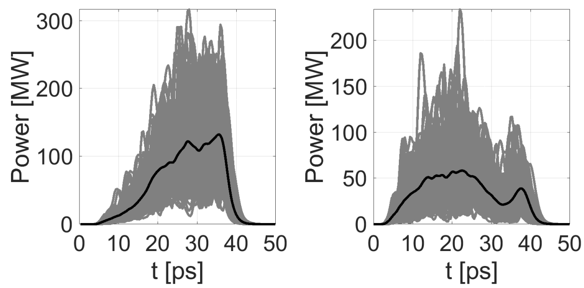

Figure 3: Simulated temporal profiles averaged from the 100 simulations (black lines) of the FEL radiation pulse at the undulator exit based on the simulated (left) and measured (right) electron beam parameters. The grey area shows shadows of all plots from the 100 simulations.

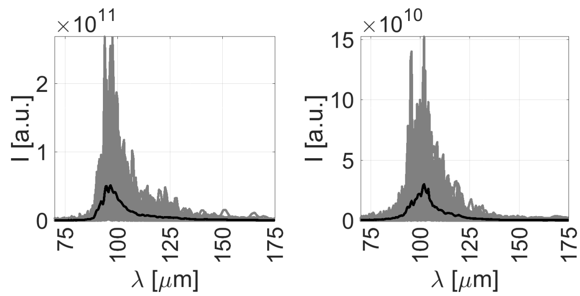

Figure 4: Simulated spectral profiles averaged from the 100 simulations (black lines) of the FEL radiation pulse at the undulator exit based on the simulated (left) and measured (right) electron beam parameters. The grey area shows shadows of all plots from the 100 simulations.

the radiation pulses fluctuate a lot. This behavior is natural for the SASE FEL process.

SUMMARY AND OUTLOOK

SASE FEL simulations for the radiation wavelength of 100 µm using the GENESIS1.3 code were performed for 2 cases of input electron beam parameters; based on the S2E beam dynamics simulation and based on the measured electron beam profiles. Different 100 initial seeds for the random number generator were used in the FEL simulations in order to simulate the fluctuations of the radiation pulse. The results show that, for both case, a radiation pulse energy of about 2 mJ can be achieved within a undulator length of 5 m with about 10% fluctuation. However, the temporal and spectral profiles of the radiation pulse fluctuate a lot which is a natural behavior of the SASE FEL process.

This fluctuation can be significantly reduced by using seeding FEL methods. General ideas of the seeding methods are presented in [11]. There are few interesting options to generate a pre-modulated electron beam for the seeding FEL at PITZ; using of a modulated photocathode laser pulse [12], using of wakefields from a corrugated pipe [13] and from a dielectric-lined waveguide [14, 15]. Studies on these options are ongoing.

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