SIMULATIONS FOR THE FEL TEST FACILITY AT MAX-LAB WITHIN EUROFEL

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Abstract

Within the EUROFEL project an HGHG FEL will be constructed at MAX-lab in collaboration with BESSY. To predict FEL performance and stability, simulations of the photo injector, linac, recirculator, transport and undulator sections that comprises the injector FEL, has been carried out. A first step of start-to-end simulations with preliminary results will also be presented.

The FEL undulators[4] will be placed inside the MAX II ring, approximately 40 m from the injector. There exists an electron beam transport system with suitable beam optics to reliably transport the electron beam from the injector to the undulators. This part is also simulated using ELEGANT. Just before the first undulator, the electrons will do a small bend so that a seed laser beam can be inserted.

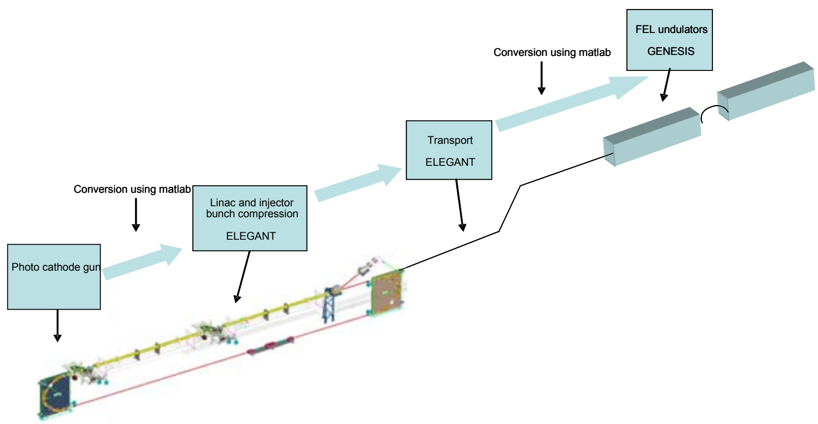

Figure 1: Overview of the FEL setup and start-to-end simulations.

INTRODUCTION

The creation of short, intense and coherent radiation pulses with the development of Free Electron Lasers is an important step for future light sources. In collaboration between the synchrotron radiation laboratory MAX-lab in Lund, Sweden and the Berliner Elektronenspeicherring Gesellschaft für Synchrotronstrahlung (BESSY) in Berlin, Germany, a test facility for a seeded High Gain Harmonic Generation (HGHG)-FEL will be built over the coming two years at the MAX-laboratory in Lund. The test facility provides the opportunity for investigating the design and function of various aspects of the FEL and also for testing simulation codes and scripts.

For the experiment, the already existing MAX injector[1]with 400 MeV electrons will be used with a new low emittance photocathode gun installed [6]. The gun has been simulated using the code ASTRA[2]. The injector further consists of two 5.2 m long linac structures each providing for a beam energy of up to 125 MeV. When the electrons have passed both linacs they are bent into a recirculator, turning them around 360 degrees and passing them through the linacs one more time. This gives a total beam energy of 400-500 MeV. Using an off crest RF phase in the linacs and the magnetic optics in the recirculation blocks, longitudinal compression of the electron bunch can be achieved. This is simulated using ELEGANT[3].

The FEL section comprises of one planar and one APPLE II type undulator and an intermediate magnetic chicane. This will make up a one step HGHG FEL, seeded with a Ti:Sapphire laser at 266 nm and giving for the third harmonic, radiation of 88nm. This part is simulated with the code GENESIS 1.3 [5]

A schematic view of the FEL setup and the start-to-end simulations can be seen in figure 1.

INJECTOR

The Gun

In order to produce a transversely and energetically collimated electron beam, the electrons are generated in a low emittance photocathode gun. The beam dynamics in the gun is simulated with the code ASTRA which takes in to account space charge effects. The gun is a 3 GHz 1.6-cell cavity, mounted slightly off axis, with a copper cathode illuminated by a ten ps long Ti:Sa laser pulse. This produces bunches with a total charge of 0.5 - 1 nC. After the gun the electron beam is bent to go centred through the linac. This bend is simulated in ELEGANT where a conversion of the output file between ASTRA and ELEGANT is done in MATLAB. The particle file is then converted back to ASTRA input and run trough the first linac in the MAX-injector. The beam parameters at the exit from the gun can be seen in table 1 and figure 2.

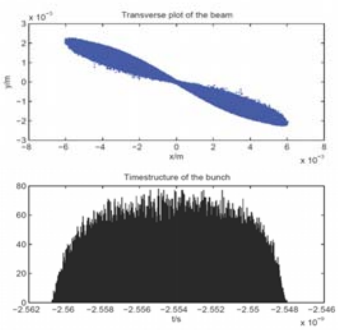

Figure 2: Electron bunch after the gun.

Table 1: Beam Parameters after the Gun

Energy	8 MeV
Energy spread	3 %
Normalized emittance ε_N	3 mm mrad
Charge	0.5 nC
Pulse length	11 ps
Peak current	45 A

The Recirculator

Since a high peak current is important for FEL efficiency, the electron bunches have to be compressed after the gun. Bunch compression is achieved using the linacs and the magnetic optics in the recirculator. The method is similar to the common bunch compression schemes in linear accelerators [7]: the electric field in the linac is given such a phase that an energy chirp is induced in the electron pulses. Through the quadrupoles and dipoles in the recirculator block, this chirp can then be rotated time wise to result in a very short pulse. Because of the sinusoidal shape of the accelerating field, the energy spread will not be completely linear but some second order effects will occur. These second order effects can be compensated by the use of sextupole magnets which introduce second order corrections and straighten the energy chirp up to a line. In the MAX-injector sextupoles are incorporated in some of the quadrupoles in the recirculation blocks and are not separately tuneable. They can thus not be used to completely linearize the second order effects, but they do contribute a bit towards higher peak brilliances. With separately tunable sextupoles linearization more corresponding to that of a higher order cavity can be done.

Approximately 25% of the bunch charge can be confined within the usable part of the bunch. This way, bunch lengths shorter than 300 fs and peak currents of 300 A can be obtained. Table 2 and the left side of figure 3 show the beam at the exit of the recirculator.

Table 2: Beam Parameters after the Recirculator

Energy	400 MeV
Energy spread	0.1 %
Normalized emittance ε_{Nx}, ε_{Ny}	3 mm mrad, 8 mm mrad
Bunch charge in peak	0.12 nC
Pulse length	400 fs
Peak current	300 A

Transport

The transport from the injector to the undulator section is about 40 m and includes a vertical lift of the beam from the cellar to the ground floor. This lift is done with an achromatic dogleg [8] consisting of two 15 degree bends with 5 quadrupoles in between. The middle quad is used to control the beta-function while the two outer ones are used to close dispersion after the second bend. To avoid space charge effects in the centre of the dogleg, where the beta function can hit a very low minimum, the two quads on either side of the middle are used for modification of the beta function.

The transport should introduce minimal changes to R_{56} and T_{566} and it should give the beta function a suitable minimum in the first FEL undulator and keep the energy spread low. Almost no influence on the beam should occur in the small bend before the undulator section where the seed laser is introduced.

The demands on the electron beam before entering the undulators are low emittance, low energy spread, high peak current, and small transverse size. The beam just before a MATLAB conversion to a GENESIS compatible input format is shown in figure 3, right side, and table 3.

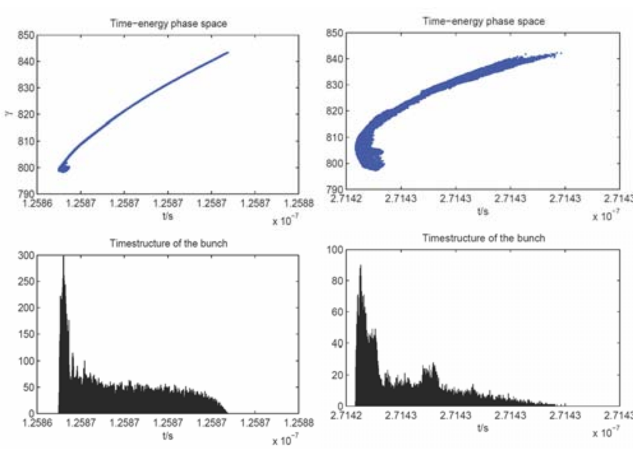

Figure 3: Left: Electron bunch after the recirculator, right: electron bunch before undulator section.

Table 3: Beam Parameters after the Transport

Energy	400 MeV
Energy spread	0.05 %
Normalized emittance ε_{Nx}, ε_{Ny}	5 mm mrad, 23 mm mrad
Bunch charge in peak	0.16 nC
Pulse length	500 fs
Peak current	300 A

FEL UNDULATOR SECTION

The FEL section comprises of two undulators and an intermediate magnetic chicane. In the first undulator, called modulator, the electron beam copropagates with a strong seed laser of 266 nm wavelength and is modulated in energy. The particles then pass through the magnetic chicane which serves as a dispersive element. It consists of four dipole magnets and introduces an energydependant longitudinal delay of the electrons: the unmodulated particles are bent into a longer trajectory than the higher energy particles so that the beam is redistributed longitudinally. The process is referred to as "(micro)bunching". The modulator is tunable in such a way that maximal bunching occurs either at the resonant frequency of the modulator or at higher harmonics (High Gain Harmonic Generation). In the MAX-lab FEL experiment, the third harmonic will be used, thus efficiently shortening the output wavelength of the FEL to 88 nm. In the second undulator, called radiator, the bunched beam will then emit intense, coherent radiation at the shorter wavelength with an output power in the megawatt-range.

The 6 dimensional phase space file from elegant is converted into a genesis input file by cutting out the seeded part of the beam +/-50fs and splitting it up into a collection of temporal slices. For each slice, the relevant beam parameters are calculated externally and delivered to a GENESIS compatible input file.

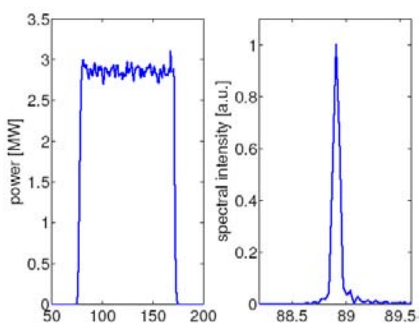

Figure 4: Temporal and spectral power distributions of FEL pulse at exit of radiator.

Simulation Results

Due to the fact that the simulation work is still ongoing, the results for the FEL section presented in this section were achieved without a formal start-to-end-transport of the original input bunch from ASTRA to GENESIS. However, the beam parameters gained by the slice analysis were used to perform fully time-dependant simulations taking into acount the seed laser beam temporal profile. A 95%-emittance of 3 mm mrad (normalized) was assumed. The parameters used to model the undulator section and the magnetic chicane are listed in table 4. The setup consists of the modulator with 30 periods and the radiator with 30 periods and a longer period length.

Using a seed laser of 150MW peak power and a FWHM flat top length of 300fs, the necessary energy modulation can reliably be established within the modulator. When optimizing the magnetic chicane for maximal bunching at the third harmonic, the radiator lases at 88nm with a power level in the range of 1-10MW. Figure 4 shows the temporal and spectral power distribution at the end of the radiator.

Table 4: Parameters of the Undulator Section

Undulator period length modulator	48 mm
Undulator period length radiator	56 mm
Magnet length (4 magnets)	0.25 m
Drift length	0.13 m
Peak magnetic flux density	$1.8 \cdot 10^{-2}$ T

CONCLUSION

The FEL test facility at MAX-Lab aims at reaching an output wavelength of 88nm with a seeded HGHG FEL. Start to end tracking simulations show that the generation, compression and transport of the beam from the MAX-lab injector to the FEL undulators can be done without major harm to the electron beam quality. In fully time-dependant FEL simulations, stable lasing at 88nm could be shown. Commissioning of the FEL undulators is planned for the fall of 2006 and first beam is expected for the end of the year or the beginning of 2007.

ACKNOWLEDGEMENT

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