PROGRESS OF THE COMMISSIONING OF THE TEST FEL AT MAX-lab

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Abstract

In a collaboration between MAX-lab and BESSY a test facility for Harmonic Generation Free Electron Laser is being constructed at MAX-lab. The setup uses the existing MAX-lab injector together with a Ti:Sa 263 nm laser system, used for both the gun and seeding, and an optical klystron consisting of a modulator, a chicane and a radiator.

The different parts of the system have been installed and commissioning started during the fall of 2007. In this paper the progress of the commissioning of the Test FEL and our initial results are presented.

INTRODUCTION

The creation of short, intense, coherent radiation pulses with the development of Free Electron Lasers is an important step for future light sources. With the aim of testing the design and performance of proposed seeded FEL light sources a test facility for a seeded Harmonic Generation (HG)-FEL [1] has been constructed at MAX-lab in collaboration with BESSY. The test facility uses the existing MAX injector together with a laser system for both the gun and the seeding and an optical klystron provided by BESSY. It gives an opportunity for investigating various aspects of the FEL, such as technology, electron beam dynamics, diagnostics, and for testing simulation codes. The aim is to extract the third and fifth harmonic from a 263 nm seed laser to produce coherent radiation at 88 and 53 nm.

Commissioning of the FEL started during the fall of 2007 and many tasks has been carried out successfully. The next step is to start the seeding and harmonic generation experiments.

LAYOUT OF THE FACILITY

A schematic view of the setup can be seen in figure 1.

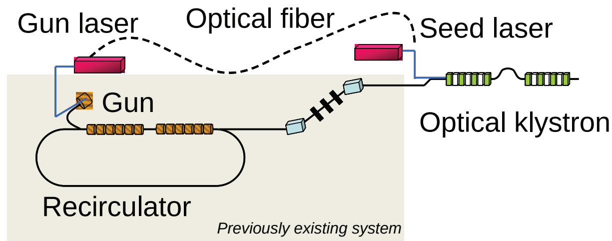

Figure 1: Overview of the FEL test facility at MAX-lab.

Previously existing injector

The MAX-lab injector [2] consists of a thermionic gun, a linac and a beam transport system. The gun is an RF gun with a BaO cathode surface that has been used mainly as a thermionic gun for injection into the storage rings. Using the gun together with a 10 ps, 263 nm laser pulse it has turned out to work very well as a photo cathode gun for injection into the FEL.

The acceleration is done in 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 around 400 MeV. The exit from the recirculator is done in a chicane and the electrons are then transported through a translating achromatic dogleg up the the location of the FEL undulators. The magnetic optics in the recirculator, chicane and dogleg provide enough first and second order momentum compaction for compressing the beam and producing a short spike of high current electrons needed for the FEL interaction.

New additions to the Test Facility

To turn the injection system into an FEL an optical klystron and a laser system to drive the seeding interaction was needed.

The optical klystron [3] was provided by BESSY and consists of one planar and one APPLE II type undulator and an intermediate magnetic chicane. Table 1 lists the properties of both undulators and the intermediate magnetic chicane.

For seeding the FEL a complete commercial Ti:Sa laser system has been purchased and installed. This laser does not only provide a 300 fs seeding pulse but also gives fully synchronized 10 ps pulses used for the photo injector. A schematic view of the laser system can be seen in figure 2.

SIMULATIONS OF ELECTRON BEAM AND FEL PERFORMANCE

Full start-to-end simulations have been performed [4] on the system including radiation output from the optical klystron. In this calculation an improved low emittance gun was used, but the results still gives an idea about what we could expect from the FEL. At 88 nm 11 MW output was achieved at a pulse length of less than 50 fs.

The gun that is currently in use can also produce low emittance electron bunches if the charge extracted from the cathode is kept low, around 0.07 nC.

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Table 1: Parameters of the undulator section of the MAX-lab-BESSY FEL when tuning the radiator to the 3^{rd} harmonic (88 nm) of the seed laser. In parenthesis, the properties for the 5^{th} harmonic (53 nm) are also given.

Modulator	
Period length	48 mm
No. of periods	30
K	2.34
Chicane (4 mag.)	
Length of magnets	12 cm
Length of drifts	40 cm
Magnetic flux density	12 mT (8)
Radiator	
Period length	56 mm
No. of periods	30
K	1.05 (0.49)

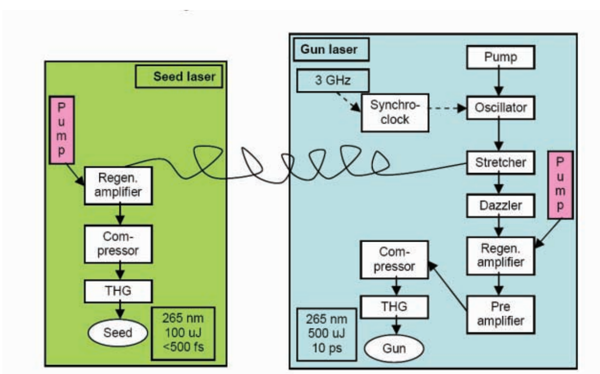

Figure 2: Schematic view of the laser system used both for the photo injector and as seed for the FEL

Particle tracking with electrons from simulations of the current gun has been carried out and the final bunch just before the optical klystron can be seen in figure 3. The calculations were made with PARMELA [9] for the gun, ELEGANT [5] for acceleration and compression, and GENESIS [6] for the time-dependent FEL simulations.

Extracting beam parameters from this bunch and making a GENESIS calculation of the third harmonic of the seed, 88 nm, gives a power output of 25 MW with a seed laser energy of 70 μJ (see figure 4). The peak power from this simulation is more that 2 times higher than from the start-to-end simulation with the improved gun. This is due to a lower average emittance and the fact that a self generated bunch was used in the calculation. Tracking the particle file through the FEL would probably give a lower peak power, but the average calculation gives a hint of what we can expect.

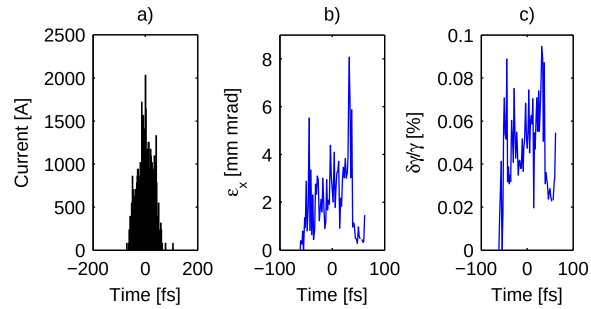

Figure 3: Current profile (a), sliced emittance in bending plane (b) and sliced energy spread (c) along the bunch extracted just before the optical klystron.

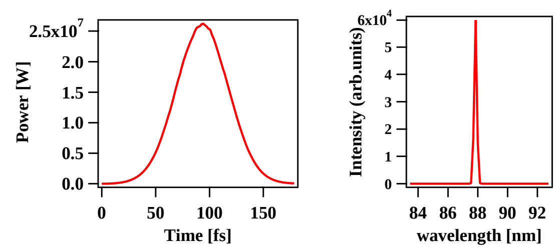

Figure 4: Power profile and spectrum of the emitted radiation at 88 nm.

PROGRESS OF COMMISSIONING

Thermionic gun

Turning the thermionic gun into a photo injector has been very successful and it seems that a high charge can be extracted from the BaO surface. Measurements of almost 1 nC of charge exiting the gun has been made at full laser energy (500 μJ). At very low laser energy (25 μJ) up to 0.5 nC has been extracted. Even this charge is too high to produce the low emittance electrons needed for FEL interaction and the charge un-sensitivity to laser power has not been fully understood yet. With lower currents from gun, the emittance that we need can be produced. An emittance scan was made for different laser energies and the result shows a decreasing trend when the laser power is lowered (see figure 5 (a)). The output from the gun at different RF-phases have also been measured by changing the delay of the laser pulse. This gives the possibility of calibrating and finding the ideal accelerating phase, which from simulations should be around 20 degrees. The result and corresponding simulation can be seen in figure 5 (b).

FEL beam line and diagnostics

The photo injector electrons have been transported through the whole FEL all the way to the beam dump. Both OTR and YAG screens are placed along the FEL line to be used for transversal and longitudinal alignment. Another tool for finding the ideal path through the beam pipe is through the Cherenkov system [7], installed by BESSY,

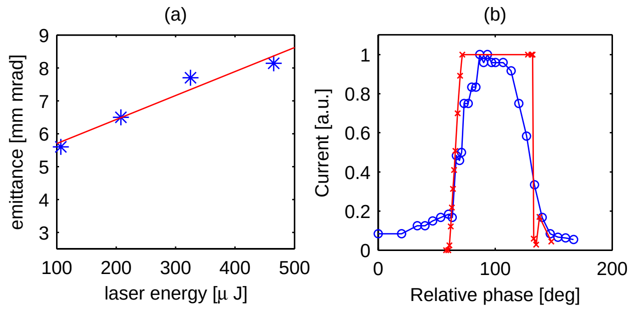

Figure 5: Part (a) shows the results from from an emittance measurement done with quad scans after the gun at different laser energies. In part (b) both measurement (circles) and simulation (stars) of the current output from the gun at different RF phases is plotted.

where radiation damage is detected on optical fibers. There are 4 fibers around the vacuum chamber and they go along the whole FEL beam line. This has been successful in giving both transversal and longitudinal information about where the beam is lost. Both undulators have been tested and calibrated and a spectral peak from spontaneous emission at 133 nm recorded with a monochromator.

Detecting bunch compression through THz radiation

All electrons in a bunch radiate coherently on the wavelengths longer than the bunch. Since the coherent radiation is proportional to the square of the number of electrons the intensity exceeds the spontaneous radiation by orders of magnitude. The coherent spectrum is truncated at long wavelengths by the cut off of the vacuum beam pipe. At short wavelengths the intensity goes down if the wavelength gets shorter than the bunch. This edge can be shifted if the bunch length is modified. The shorter the bunch is, the higher is the intensity of the THz-radiation. Measuring the THz therefore gives an indication of how compressed the bunch is [8]. A measurements of this was made where the linac phase was scanned and the intensity of the THz-radiation recorded using a He cooled bolometer.

In the start-to-end simulation beam tracking a similar scan was made for different RF phases in the linac. The square of the peak current in the calculation was normalized with emittance and energy spread to select the result that would give the most THz radiation (and also best FEL interaction). The results from the THz scan and the corresponding simulation can be seen in figure 6. The agreement between measurements and simulations is very good, and is a clear evidence that the optics for bunch compression works as predicted.

SUMMARY AND OUTLOOK

During the last year, the construction of the HG FEL test facility at MAX-lab has finished and commissioning has

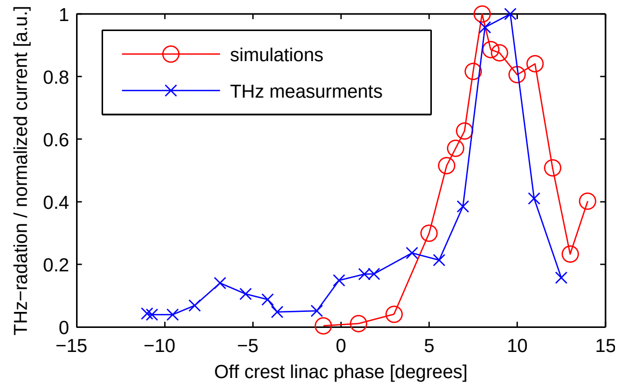

Figure 6: The blue markings in this plot show the result from a THz measurement and the red marks shows the square of the peak current, normalized with energy spread and emittance, from simulations.

started. The photo injector, beam transport and compression, and FEL undulators have been tested successfully. The next step will be to start seeding the electron bunches with 263 nm laser pulses. The setup for transversal and longitudinal overlap is discussed in [10]. The first step will be to detect radiation at the second harmonic 131.5 nm, before we start trying to produce shorter wavelengths with the third and fifth harmonic at 88 and 53 nm.

In a later phase in the project a HHG (High Harmonic generation) chamber will be used for seeding the FEL at lower wavelength in collaboration with Lund Laser Center [11].

REFERENCES

[1] L.H. Yu, Phys. Rev A 44 (1991) 5178.

[2] S.Werin et al., “Commissioning of the 500 MeV Injector for MAX-lab”, EPAC 2004.

[3] J. Bahrdt et al., “Undulators for a Seeded HGHG-FEL at MAX-lab”, EPAC 2006.

[4] S. Thorin et al., “Start-to-end simulations for a seeded harmonic generation free electron laser”, Phys. Rev. ST Accel. Beams 10, 110701 (2007).

[5] M. Borland, “Elegant: A flexible SDDS-Compliant Code for Accelerator Simulation”, APS LS-287, 2000.

[6] S. Reiche, “GENESIS 1.3: a fully 3D time-dependent FEL simulation code”, Nucl. Instr. and Meth. A 429 (1999) 243.

[7] M. Körfer, W. Göttmann, F. Wulf, J. Kuhnhenn, Proceedings of DIPAC 2005, Lyon, France, 2005, p301.

[8] Holldack et al. PRL 96, 054801 (2006)

[9] PARMELA, K.R. Crandall, J.H. Billen, et. al Los Alamos National Laboratory, USA.

[10] N. Cutic et al., “Seeding at the test-FEL at MAX-lab”, These proceedings.

[11] A L’Huillier, F. Krausz, “High-Order Harmonic Generation, Handbook of Lasers and Optics” (ed. F. Träger), Springer, New York (2007) p.219