COMMISSIONING OF THE TEST FEL AT MAX-LAB

F. Curbis, N. Čutić, F. Lindau, S. Thorin, S. Werin, MAX-lab, Lund, Sweden
M. Abo-Bakr, J. Bahrdt, K. Holldack, BESSY GmbH, Berlin, Germany

Abstract

An installation for testing techniques related to seeding and harmonic generation has been completed at MAX-lab. The aim is to study the processes around seeded harmonic generation at 130/88/54 nm, the 2/3/5 harmonic of a Ti:Sapphire laser. During the spring 2008 the commissioning work has begun and this paper will report on the progress.

The test FEL is built around the existing linac injector at MAX-lab. This source can provide 4-500 MeV electrons from an RF-gun. A combined laser system both driving the photo cathode in the gun and, synchronised via an optical fibre, the seed laser pulse has been put into operation. An optical klystron, consisting of two 30 period undulators and a 4-magnet chicane, is in operation. Beam loss monitors along the optical klystron are in use and a THz system for additional synchronisation studies installed.

Results from electron beam optics and operation generating spontaneous radiation is already available and synchronisation results immediate. The work is in progress and new results are added continuously to the portfolio.

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 relevant for the 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 new laser system for both the gun and the seeding and an optical klystron provided by BESSY. The aim is to extract the second, third and fifth harmonic from a 263 nm seed laser to produce coherent radiation at 133, 88 and 53 nm. It gives an opportunity for investigating various aspects of the FEL; RF gun, gun lasers, bunch compression, synchronisation, stability, diagnostics and test of simulation codes.

Commissioning of the FEL started during the winter of 2007-8 and many tasks have been carried out successfully. The next step is to start the actual seeding and harmonic generation experiments. The overall performance of the subsystems has been explored. The current gun is able to deliver low emittance at reduced charge (<0.1nC). In simulations the set up is capable of providing <400 fs pulses with ε_N< 5 mm mRad and a harmonic beam of several MWs in the third harmonic [2, 6]

The project is run also with the focus on preparing technologies for the MAX IV, BESSY FEL projects and supporting the training of PhD students.

LAYOUT OF THE FACILITY

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

Accelerator and transport

The MAX-lab injector [3] 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 (normally at 100 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

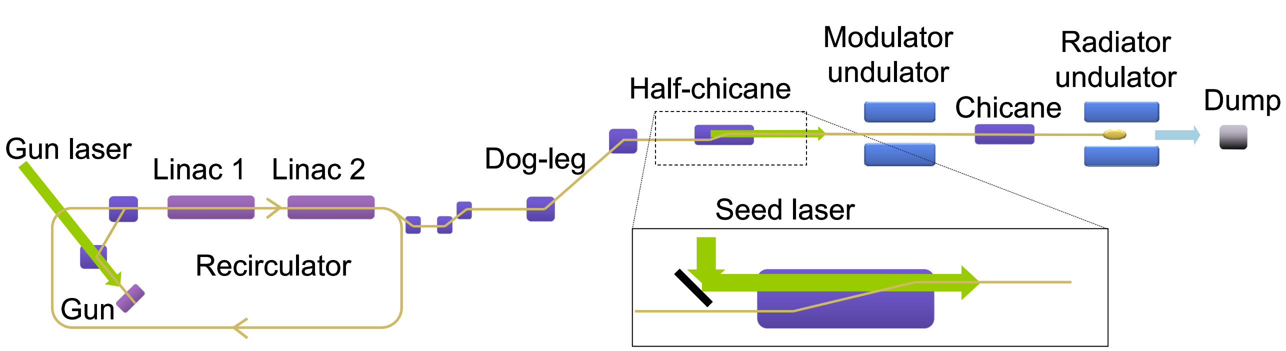

Figure 1. Layout of the MAX-lab test-FEL.

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.

FEL and OK

The main component of the test facility is the optical klystron [4] which was provided by BESSY and consists of a modulator undulator (planar type) and a radiator undulator which is an APPLE II type undulator plus an intermediate magnetic chicane. Table 1 lists the properties of both undulators and the intermediate magnetic chicane.

Table 1. Parameters of the undulator section when tuning the radiator to the 3rd harmonic (88 nm) of the seed laser. In parenthesis, the properties for the 5th 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(8) mT
Radiator	
Period length	56 mm
No. of periods	30
K	1.05 (0.49)

Laser system

The laser system is a combined system which provides both the RF gun pulse and the seed laser pulse for the Harmonic generation. The two parts are placed almost 100 m apart and synchronised via a fibre link.

A laser oscillator (Femtolasers Synergy, 93.71 MHz, 790 nm central wavelength, bandwidth 13 nm FWHM) is placed in the gun laser hutch and locked to the 3 GHz signal generated for the RF system (gun, linacs) with a time jitter less than 1.4 ps. The jitter is due mainly to the RF generator. The oscillator is common for both the seed and the gun laser.

The pulses of the oscillator are stretched and split in two branches. In the gun laser branch the pulses are shaped in a Dazzler, amplified, compressed and tripled to 263 nm giving up to 500 uJ in a 10 ps pulse.

The other branch is sent through an elliptical core polarization maintaining optical fiber 90 meters to the seed laser where it is amplified, compressed and tripled to 263 nm in a pulse of 350 fs and ~100 μJ energy. A beam transport system delivers the seed laser pulse into the accelerator system (see figure 2).

The gun laser system is also used for the initial tests of the FERMI@Elettra RF gun, in a temporary set up at MAX-lab in an Elettra – MAX-lab collaboration.

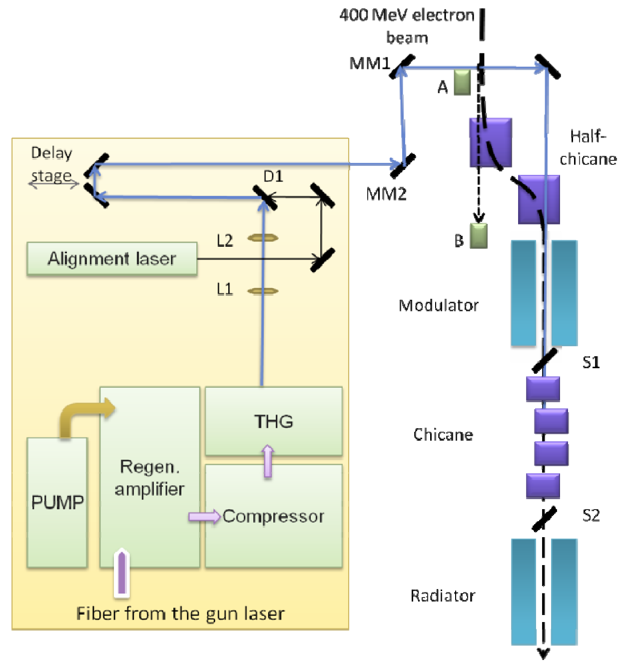

Figure 2. Seed laser layout and optics to focus the laser beam into the modulator. L1 and L2 are lenses for focusing of the laser beam inside modulator. MM1 and MM2 are remote controlled mirrors. S1 and S2 are screens used for alignment. A and B are diodes used for time synchronization.

OVERVIEW OF THE COMMISSIONING

The commissioning process started during the winter 07-08 and has been performed alternating with the routine operation for users of the MAX-lab facility. The changed operation mode for the RF-gun from thermionic to 10 ps photocathode has been achieved. The electron beam has been transported through the complete system. The magnetic systems, especially the undulators and the chicane, have been operated successfully [5]. The next step is the final adjustment of the seed laser system.

RF gun system

Turning the thermionic gun into a photo injector has been very successful and 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. Still at rather low laser energy (25 uJ) up to 0.5 nC has been extracted. Even this charge is too high to produce the low emittance 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. The emittance has been measured by a quad scan and shows an expected current (laser energy) dependence (fig 3b). The current as a function of laser pulse phase relative the RF phase has been recorded (fig 3a) which also shows an expected performance and allows for a controlled choice of phase. The smallest emittance should theoretically be achieved at around 20 degrees.

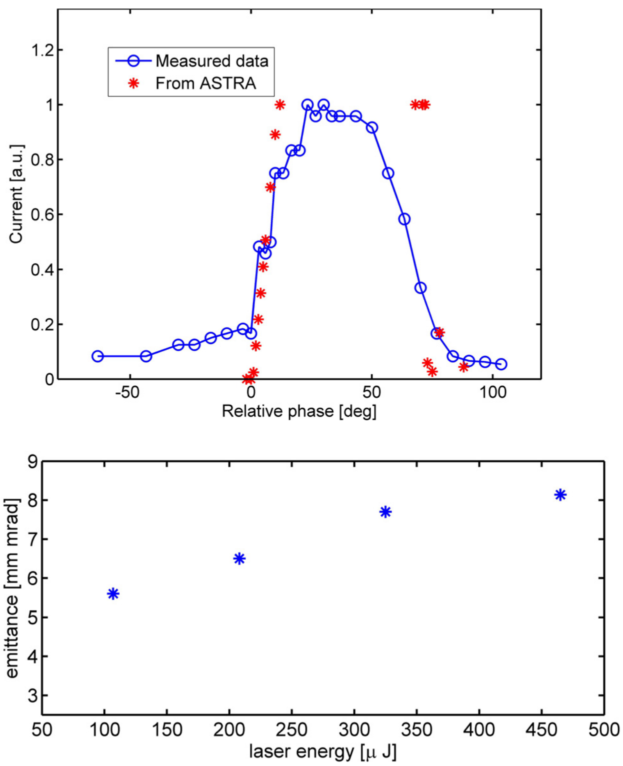

Figure 3. RF gun performance. (a) Current output from the gun at different RF phases (circles-measurement, stars-simulation). (b) Emittance as a funcition of laser energy (charge significantly below 0.5 nC).

Transport and compression

The electron beam has been transported up through the Optical klystron. The compression optics has been quantitatively explored by detecting a THz signal proportional to the bunch length [2, 5].

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 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 [7]. 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 a start-to-end simulation a similar scan was made for different RF phases in the linac. The results from the THz scan and the corresponding simulation can be seen in figure 4. The agreement between measurements and simulations is very good, and is a clear evidence that the optics for bunch compression works as predicted.

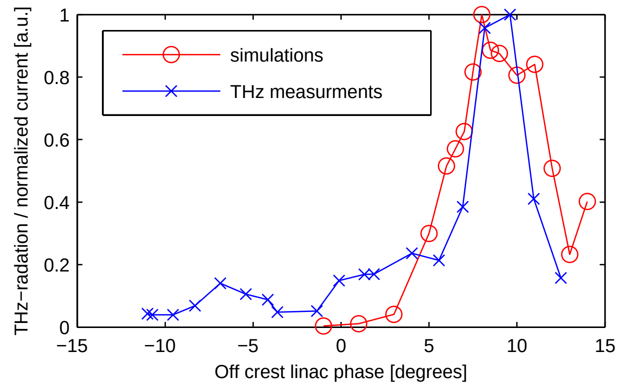

Figure 4. The THz signal intensity as a function of linac phase (providing the energy chirp for compression).

As a tool to find the ideal path a Cherenkov system [8] has been installed by BESSY. In this radiation damage is detected in 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 [5].

Synchronisation

Considering the seed laser bunch length (350 fs) and the electron bunch length (less than 1ps), it is obvious that synchronization will be challenging. A rough adjustment method of the arrival of the electrons has been elaborated, providing timing information approaching 200 ps. Two fast Si PIN photo diodes, one hit by the seed laser and one by the electron beam directly, will be connected to a 5 GHz oscilloscope. (A and B in Fig. 2) The very fast rise time has been recorded using electrons (see Fig 5). From 200 ps a a sweep of the temporal overlap using a delay stage will be done while detecting increase in coherent radiation.

Alignment

The transverse alignment of the seed laser to the electron beam will be done via two YAG screens which can detect both electrons and 263 nm laser photons (screen S1 and S2 in the Fig 2)

During first operation the seed laser pulse will not be fully compressed or focused to make overlapping (longitudinally and transversely) easier. Stretching of the seed laser pulse to 1ps and weaker focusing (1.5 mm waist) is planned. Preliminary time-dependent simulations performed using GENESIS 1.3 [9] show that the induced energy spread (see Fig 6) is still sufficient to generate the third harmonic (88 nm) of the seed laser in the radiator.

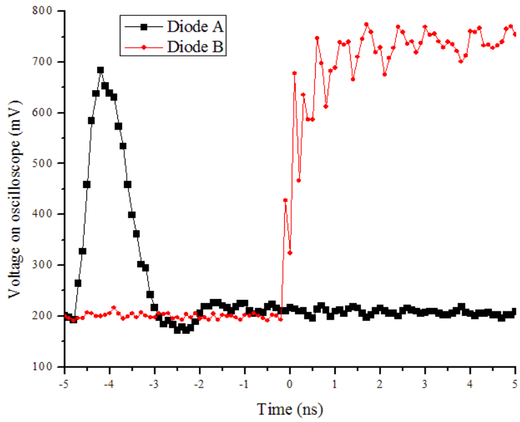

Figure 5. Photo diode signals while hit by electrons directly. Arrival information is between 200 and 500 ps. (The different shape of the signal is due to different termination of the signals).

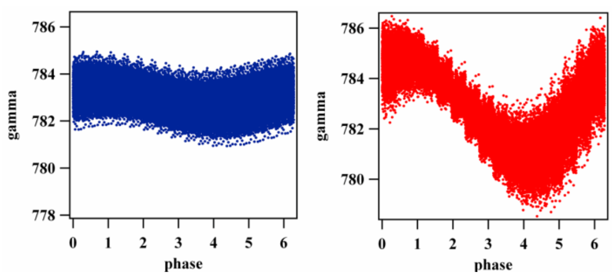

Figure 6. Left image shows the energy modulation after the modulator using a relaxed seed laser pulse (50 MW, 1 ps, 1.5 mm waist). Energy modulation in the “ideal case” (200 MW, 300 fs, 0.5 mm waist).

Monochromator system and spontaneous emission

A small grating monochromator system is attached after the radiator undulator. The system can cover the most urgent range from 88-266 nm (1st to 3rd harmonic) and give a resolution power to resolve the linewidth narrowing for the HG photons at 88 nm. The system can be equipped with either a photo multiplier or a photo diode.

Calibration of the wavelength of the spontaneous radiation from the modulator and radiator has been performed using a photo multiplier.

Further improvements

To improve synchronization of the pulses and allow stability studies a chamber with ZnTe and GaP crystals will be installed to make electro-optical measurements (fig 7). As laser source An infrared laser pulse will be extracted before the tripling in the seed laser and after polarization sent through one of the crystals. The goal is to get to picosecond range in synchronization precision.

As a second stage of the test facility seeding with high harmonics generated by a laser in a gas jet at around 100 nm is planned [10]. This development phase is funded in a collaboration with the Lund Laser Center.

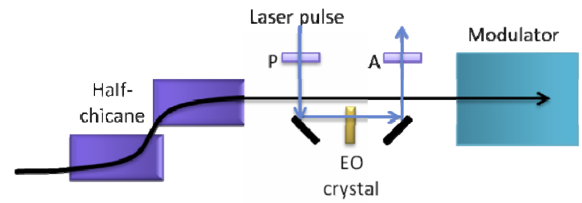

Figure 7. Schematics of the planned electro-optical technique to synchronize the seed laser pulse and electron bunch more precisely.

SUMMARY

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

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