THE TEST FEL FACILITY AT MAX-LAB

Sverker Werin, Nino Cutic, Filip Lindau, Sara Thorin, MAX-lab, Lund, Sweden
Johannes Bahrdt, Karsten Holldack, Helmhotz Zentrum Berlin/BESSY GmbH, Berlin, Germany
Christian Erny, Lund Laser Centre, Lund, Sweden*

Abstract

A facility for seeding and harmonic generation utilizing an optical klystron is under commissioning at MAX-lab. The facility utilizes the 400 MeV linac accelerator, improved operation of an RF-gun, an undulator system of two undulators and a magnetic chicane and combined laser system for gun and seeding. The goal is to seed the electron beam at 263 nm and generate the harmonics 2-5 (131-53 nm). Currently the system is under commissioning. We report on the operation of the sub-systems and the latest results on the commissioning towards achieving harmonic generation.

INTRODUCTION

Future light sources, such as Free Electron Lasers, will generate short, intense, coherent radiation pulses with the development of high brightness electron sources. With the aim of testing the design and performance relevant for future 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. Despite this the expected generation of coherent photons in the harmonics still remain. The main issues during the past year has been:

- Improved control of temporal overlap [2]
- Improved stability of the klystrons.
- Improved temporal laser stability due to a new low noise 3 GHz generator.
- Tehcnical improvements of the diagnostics systems
- Improved laser stability.
- Better characterisation of the electron source [3]

* This work has been partially supported by the EU Commission in the sixth framework program, Contract no. MEST-CT-2005-020356, and the Swedish Research Council.

Unfortunately a new limiting factor has arisen, with a damaged grating in the monochromator system. This has prevented us from crosschecking the electron energy or undulator gaps to assure the resonance conditions.

LAYOUT OF THE FACILITY

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

Accelerator and Transport

The accelerator system [4] consists of a RF gun, a linac and a beam transport system. The gun is equipped with a BaO cathode surface that previously has been used only as a thermionic gun for injection into the storage rings; MAX I, MAX II and MAX III. By illuminating the gun with a 10 ps, 263 nm laser pulse photo electrons are extracted for injection into the FEL. The energy at the gun exit is around 1.7 MeV

The main acceleration is done in two 5.2 m long linac structures each providing 100 MeV. When the electrons have passed both linacs they are bent by a recirculator, and pass 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 to 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.

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)

FEL and Optical Klystron

The main component of the test facility is the optical klystron [5] which was provided by BESSY and consists of a modulator undulator (planar type) and a radiator undulator which is an APPLE II type plus an intermediate magnetic chicane. Table 1 lists the properties of both undulators and the intermediate magnetic chicane.

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 of 200-500 fs. This jitter level has been achieved by an improved RF generator.

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.

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 [6].

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.

A better characterisation has recently been done of the system.[3] Most interesting to note is the good performance of the system with a BaO cathode. Charge and emittance necessary for the Test FEL has been achived (see fig 2). The system also indicates that a possible operation with a lower photon energy of the gun laser system could be possible as the BaO has a work function of around 2.4 eV, well below the 4.7 eV (263 nm) of the gun laser. As laser power is no concern in our application this has so far not been pursued, but tests will be done in the future.

Still at rather low laser energy (25 uJ) up to 0.5 nC has been extracted. With lower charges from gun, the emittance that we need can be produced.

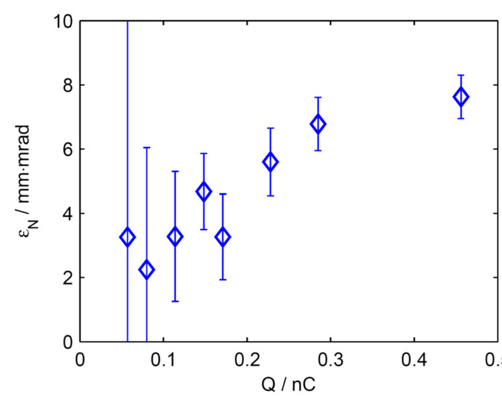

Figure 2: Normalised emittance as a function of extracted charge from the BaO cathode RF gun in photo cathode mode.

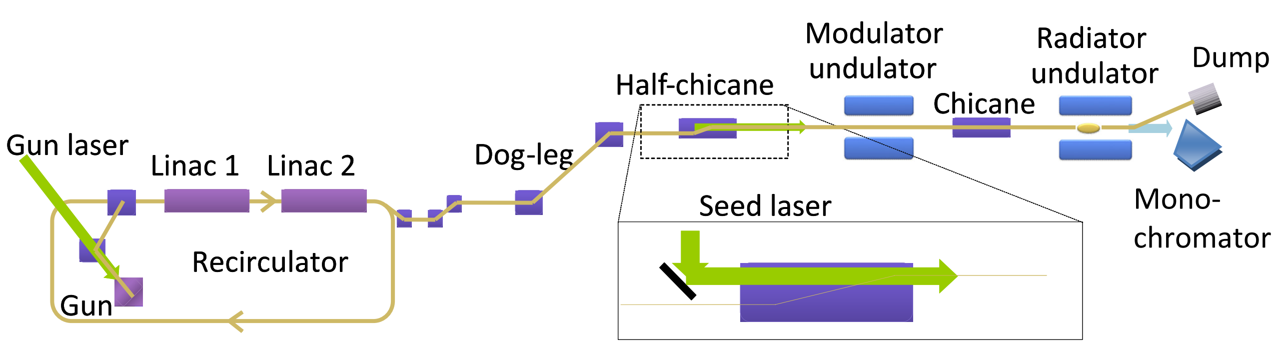

Figure 1: Layout of the MAX-lab test-FEL.

Laser System

The laser systems have been improved on a couple of points. A spatial filter has been installed on the gun laser to improve the uniformity of the focus on the cathode. A feedback system for the pointing of the seed laser has been built. The stability of the delay stages has been improved. A possibility to extract the IR pulse in the seed laser assembly has been constructed to feed the Electro Optical diagnostics system. Further the 3 GHz RF generator has been replaced to achieve a lower phase noise. This resulted in the jitter level of the Femto lock laser system dropping from 1.5 ps to below 500 fs.

Improvement to the RF Drive Systems

On the RF drive side we have mainly worked to improve stability. Initially the system showed an energy jitter resulting in position jitter in the undulators. It is unknown, but expected, that this jitter also gave an arrival jitter of the pulse.

The high tension power supplies for the linacs have been replaced. A solid state modulator (by Scandinova) has been installed on the gun klystron with the aim of improving the stability and for tests in connection to the MAX IV project. A new circulator has been installed on the RF gun waveguide.

Transport and Compression

The electron beam has earlier been transported up through the optical klystron. The compression optics has been quantitatively explored by detecting a THz signal proportional to the bunch length [6].

As a tool to find the ideal path the Cherenkov system [7] installed by BESSY is used as additional diagnostics tool. 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 [6].

The energy spread of the electron beam has been recorded via screen placed after the dump magnet, where the dispersion is 0.24 m. The energy spread is estimated to stay below $\sigma_E/E=5*10^{-3}$. (Only an upper limit is achievable as the emittance and beta functions are not completely known at this position.)

Alignment

The transverse alignment of the seed laser to the electron beam is done via two YAG screens which can detect both electrons and 263 nm laser photons. These screens are flanking the modulator undulator and the resolution is enough to resolve the laser focus.

Monochromator System and Spontaneous Emission

A small grating monochromator system is attached after the radiator undulator.

The grating and the detector are now being replaced due to a damage on the grating and to allow a better matched focusing to collect more radiation. At the same time the system will be adapted for the future needs to operate down to 50 nm.

Temporal Overlap

Initially temporal overlap was determined by collecting the laser pulse and directly hitting the electron beam into the same photodiode. The arrival times could be defined with a precision down to 100 ps. The absolute arrival time was however not resolvable to this precision, probably due to different physical processes involved in the photon detection and electron detection.

The seed laser can in principle easily scan the range, but the pointing of the delay stages over 100 ps are not good enough to follow the electron beam with a focus of 0.5 mm.

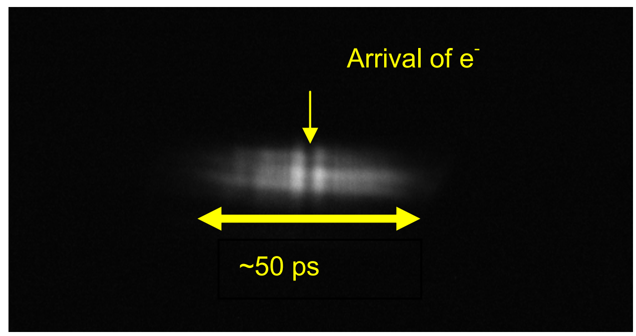

Figure 3: Chirped IR laser pulse with the polarisation rotation in the middle, indicating the arrival time of the electron pulse.

To improve synchronization of the pulses and allow stability studies a chamber with a ZnTe has been installed to make electro-optical measurements [2] (Fig 3). An infrared laser pulse, extracted before the tripling in the seed laser, is chirped with a 50 ps duration and sent through the crystal. Due to induced birefringence when the electrons pass the crystal part of the infrared pulse is rotated in polarisation. The arrival time of the electrons relative the IR pulse can thus be detected with a precision <10ps. The overlap between the IR pulse and the seed laser pulse can be determined via cross-correlation to the same precision.

The seed laser delay stage can now with retained beam pointing perform the remaining scan.

SUMMARY

During the last year commissioning of the test facility at MAX-lab has started. The photo injector, beam transport and compression, and FEL undulators are all operated. Diagnostic systems have been improved. At the moment the monochromator system is upgraded mainly due to a damaged grating.

The initial idea to scan the timing overlap within a fairly large region has proven not to be feasible. Effort has thus during the last year been put mainly into reducing the ranges over which scanning has to be made. Transverse overlap and time overlap are now defined to a higher degree. Remaining is the final calibration of the undulator gaps, for which the monochromator grating is needed.

The next step will be to continue the efforts for seeding the electron bunches with 263 nm laser pulses.

REFERENCES

[1] L.H. Yu, Phys. Rev A 44 (1991) 5178.
[2] Nino Cutic, Filip Lindau, Sara Thorin, Sverker Werin, Christian Erny; An electro-optical system for MAX-lab test-FEL facility (WEPC79), International FEL conference, Liverpool 2009 (these proceedings)
[3] Sara Thorin, Nino Cutic, Filip Lindau, Sverker Werin, Francesca Curbis; Characterisation of the beam from thermionic RF-gun adapted for photo cathode operation (TUPC33), International FEL conference, Liverpool 2009 (these proceedings)
[4] S.Werin et al., ``Commissioning of the 500 MeV Injector for MAX-lab'', EPAC 2004.
[5] J. Bahrdt et al., ``Undulators for a Seeded HGHG-FEL at MAX-lab'', EPAC 2006.
[6] J. Bahrdt et al., Undulator System of the Seeded HGHG-FEL at MAX-lab (TUPPH006), FEL 2008
[7] M. Körfer, W. Göttmann, F. Wulf, J. Kuhnhenn, Proceedings of DIPAC 2005, Lyon, France, 2005, p301