THE TEST FACILITY FOR HARMONIC GENERATION AT THE MAX-LAB INJECTOR LINAC *

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Abstract

A test facility for harmonic generation is being built at MAX-lab. The third and fifth harmonic, at 90 and 53 nm respectively, will be created using a fs seed laser at 266 nm. The MAX-lab injector will be operated at 400+ MeV with a photo RF gun and the optics will be retuned to achieve compression. An optical klystron will be installed comprising of two undulators and a chicane.

OVERVIEW AND SCOPE

The BESSY FEL project [1] and the MAX IV proposal [2] are both focused on seeded FEL sources as part of the facilities. In the aim of improving the designs a decision was made to build a test facility for harmonic generation at MAX-lab.

The MAX injector system [3] is a recirculated linac with energy capabilities up to 500 MeV. Few other locations have this linac energy available for a test facility. The joint effort includes simulations, a new electron source, laser systems, an optical klystron and experimental activities.

The test facility is intended to use an electron beam of at least 400 MeV with an emittance of 3 μmRad and a bunch length around 500 fs. It will be injected into an optical klystron consisting of a modulator undulator, a chicane and a radiator undulator. A fs seed laser at 266 nm will be used and harmonic generation at 90 nm and later 53 nm will be studied.

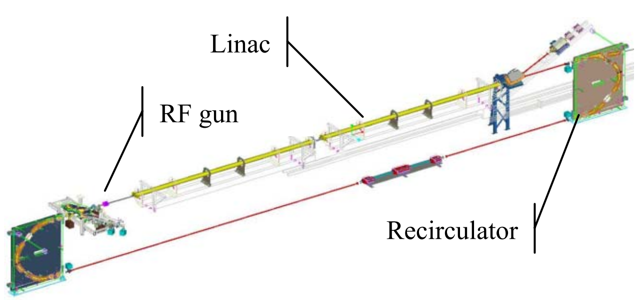

Fig 1. The MAX injector.

The FEL Principle

The FEL section consists of an Optical Klystron where in the first undulator, called modulator, the electron beam co-propagates 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 energy-dependant 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 bunching is tunable to achieve a maximal Fourier component at either the resonant frequency of the modulator or at higher harmonics. 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. Substantial development of this method, HGHG, has been done at BNL [4].

THE ACCELERATORS

While most of the accelerator systems are already at hand at MAX-lab some additions and alterations are necessary. These mainly regard a new photo cathode RF gun [5] and finding a new optics [6] which creates compression and transports the bunch to the optical klystron.

The Gun Pre Injector

In order to produce a transversely and energetically collimated electron beam, the electrons will be generated in a low emittance photocathode gun. The gun is a 3 GHz 1.6-cell cavity, mounted slightly off axis, with a copper cathode illuminated by a ten ps long laser pulse at 266 nm. This produces bunches with a total charge of 0.5 - 1 nC. The beam parameters at the exit from the gun can be seen in table 1.

Table 1: Beam parameters after the gun (simulated)

Energy	3.7 MeV
Energy spread	3 %
Normalized emittance ε_N	3 mm mrad
Charge	0.5 nC
Pulse length	11 ps
Peak current	45 A

The emittance compensation scheme adopted is similar to the LCLS [7]. Results of the tracking are shown in fig 2.

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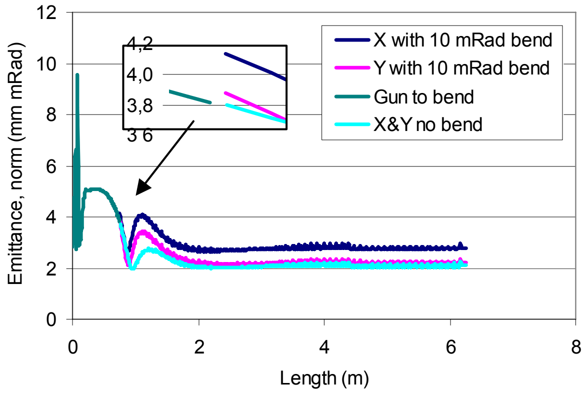

Figure 2: Emittance (normalised) (1 nC, 3.7 MeV, 10ps). off axis compensation (10mR) at 0.75 m and linac from 1m.

Linac and Recirculator

The linacs and recirculator system in the MAX-injector have been in operation for several years. They routinely deliver 380 MeV as injector for MAX I and II. They are currently being conditioned above 400 MeV.

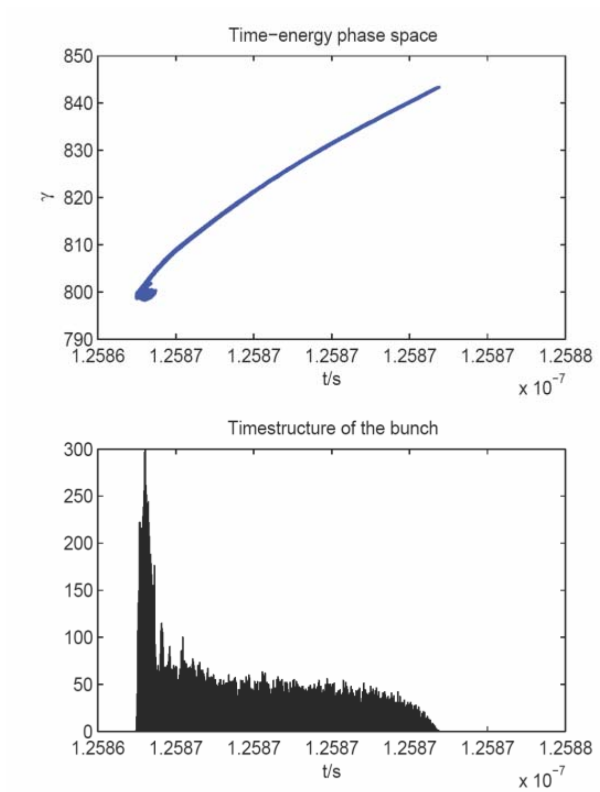

Figure 3: Electron bunch after the recirculator.

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 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 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 OPTICAL KLYSTRON

Existing magnet structures will be used to build the undulators. A pure permanent magnet (PPM) structure has been loaned from the ESRF to be used in the modulator. The radiator will be equipped with the APPLE structure of the BESSY UE56-1. The parameters are summarized in table 3.

Table3: Parameters of the undulators and the chicane

Modulator	
Period length	48 mm
Number of periods	30
Minimum gap	10 mm
Maximum K-parameter	4.3
Radiator	
Period length	56 mm
Number of periods	30
Minimum gap	12 mm
Maximum K-parameter	4.3
Chicane	
Number of magnets	4
Type of magnet	H-frame, electromagnet
Gap	15 mm
Maximum field	0.2 T
Distance between magnets	400 mm

Both undulators will have a motorized gap drive. The radiator provides also a motorized phase variation for polarization control. The modulator is moved only in case of an electron energy change whereas the radiator has to be tuned also when the harmonic number of the radiation or the state of polarization is changed.

The Chicane

The magnetic chicane converts the energy modulation of the electron beam into a spatial modulation. Optimum bunching is achieved if the energy modulation dominates the energy spread times the harmonic number n:

$$\Delta\gamma/\gamma \geq n \cdot \sigma_\gamma$$

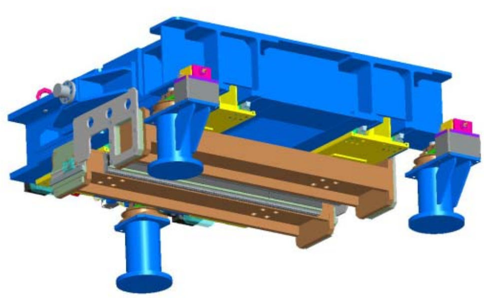

Figure 4: Modulator in operating position.

With a relative energy spread of $\sigma_\gamma = 5 \cdot 10^{-4}$ an energy modulation of at least $\Delta\gamma/\gamma = 1.5(2.5) \cdot 10^{-3}$ is needed to operate on the third (fifth) harmonic. This defines the laser power.

The maximum bunching appears for a path length difference of $\Delta L = \lambda_{photon}/4$ between modulated and non modulated electrons. The chicane is optimized such that $\Delta L = \lambda_{photon}^{1st}/4 = 67nm$ can be reached with 500MeV electrons and an energy modulation of $\Delta\gamma/\gamma = 1.0 \cdot 10^{-3}$. For higher harmonics (shorter wavelengths) $\Delta L \geq \lambda_{photon}/2$ can be produced and overbunchig effects can be studied.

Mechanical Layout

The electron beam height at the HGHG-FEL is only 400 mm and conventional undulator carriages cannot be used. Therefore, a new carriage has been developed which can cope with this geometry (figure 4). The same structure is used for both undulators.

The two undulators will be measured and shimmed at the existing measurement bench at BESSY. For this purpose the undulators have to be flipped into upright orientation (figure 5). At MAX-lab the final magnetic measurements will be performed in the operating position using a pulsed wire system.

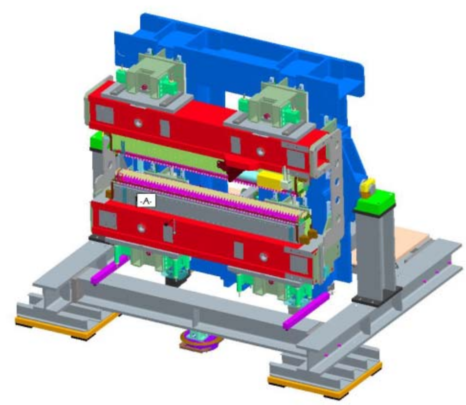

Figure 5: Radiator in measurement position.

LASER SYSTEMS

A combined laser system for the gun and the seeding of the HG-FEL has recently been sent out with an invitation to tender. We foresee a common system locked to the RF of the accelerators to better than 1 ps. The system should deliver 500 µJ in a 10 ps pulse at 266 nm to the RF gun and 100 µJ in a 300 fs pulse at 266 nm to the seeding. The solution is up to the supplier while the basic thought is a centrally located oscillator locked to the accelerator RF-system and an optical distribution to the amplifiers. (Due to the commercial actions the information is minimized. Please contact the authors for more information: sverker.werin@maxlab.lu.se)

DIAGNOSTICS

The diagnostics have two main duties. The first is to control the electron beam performance and the second to assure overlap in time and space of the laser and electrons. Table 4 shows the intended methods to be used to approach the different areas.

In a resent test set-up the uncompressed bunch length at the MAX injector was measured to σ = 2.3 ps. The technique used was detecting coherent transition radiation with an interferometer [9]. This set up will now be finalized to be able to diagnose sub ps pulses.

Table 4. Diagnostics

Feature	Method
Energy spread	Dispersive section
Emittance	Q scans
Bunch length	CTR and interferometer
Current/charge	Beam transformers, Faraday cage
X and y positions	YAG/OTR screens
Alignment	Apertures for spontaneous and laser beams
Synchronization/time	Electro-optical methods Energy spread ,
Beam loss	Cherenkov fibre

THE FEL SIMULATION

For realistic simulation of the FEL, the particles were tracked all the way through gun, linac, beam transport and the undulator section using ASTRA [10], elegant [11] and GENESIS [12]. In order to study time-dependant effects of FEL interaction, the 6-dimensional phase space file from elegant was converted into a GENESIS input file by cutting out the seeded part of the beam +/-50fs and split it up into a collection of temporal slices. For each slice, the relevant beam parameters were calculated externally and delivered to a GENESIS compatible input file.

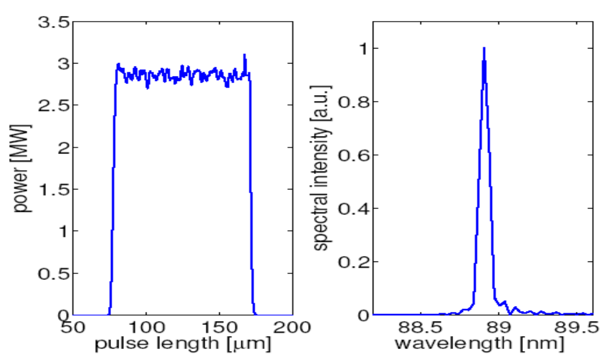

Figure 6: Temporal and spectral power distributions of FEL pulse at exit of radiator.

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 3.

Using a seed laser of 150 MW peak power and a FWHM flat top length of 300 fs, 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 88 nm with a power level in the range of 1-10 MW. Figure 6 shows the temporal and spectral power distribution at the end of the radiator.

SUMMARY

A test facility for FEL and HGHG is currently being built at MAX-lab. The coming year will be spent on installation of undulators, the new pre injector, build up of the laser systems and finalizing the diagnostics. The aim of the facility is to test and develop the techniques, but also to already at an early stage of the BESSY FEL and MAX IV projects practically address the processes.

Simulations and development of beam optics are also part of this process.

An important side effect of this project is to start the process of joining forces between the accelerator and laser science. The future of accelerators lies in many ways in starting to use lasers as natural parts of accelerator installations.

The capabilities of this installation are also such that new ideas and a continuation after the initial generation of the 3rd harmonic are a natural continuation.

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