STATUS OF THE FEL TEST FACILITY AT MAX-LAB *

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Abstract

An FEL test facility is built on the existing MAX-lab linac system in collaboration between MAX-lab and BESSY. The goal is to study and analyse seeding, harmonic generation, beam compression and diagnostic techniques with the focus of gaining knowledge and experience for the MAX IV FEL and the BESSY FEL projects. The test facility will in the first stage be using the 400 MeV linac beam to generate the third harmonic at 88 nm from a 266 nm Ti:Sapphire seed laser.

The optical klystron is installed and magnetic system, gun and seed laser systems are currently being finalised. Start-to-end simulations have been performed and operation modes for bunch compression defined. The linac and beam transport system is already in operation.

INTRODUCTION

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.

By utilising the gun, injector and linac system already available at MAX-lab a test facility for seeded FEL/Harmonic generation could be accomplished by relative low additional funding. Contacts had been taken with BESSY and with the application for the EUROFEL collaboration the project was started. The focus of the activities is to explore ideas of harmonic generation and gain experience with the FEL technology, test diagnostics and working with short pulses.

OVERVIEW OF THE PROJECT

The project is built in one major phase (I) with two improvement phases (phase II: an improved gun system and phase III: HHG seeding). The starting point is the injector built at MAX-lab in the first years of this millennium which was designed to be flexible and also allow accelerator development. A linac system was chosen together with a flexible gun mounting system equipped with a thermionic RF-gun. The source is used for injection into the storage rings (MAX I, II, III) and in the intermediate time this source is one of few available sites for tests of FEL operation at these energies.

An optical klystron system and a seed laser at 266 nm will produce the 3rd and 5th harmonic at 88 and 53 nm respectively using the 400-450 MeV electron beam. The radiator undulator in the optical klystron is not enough for amplification, and thus the activities are focused on harmonic generation. BESSY is providing the undulator and chicane system while MAX-lab is providing the electron beam and the laser system.

The aim is to study several features in the design and operation of this kind of facility. On the electron beam side: bunch compression, electron beam transport (especially with low emittance), beam stability, synchronisation and stability. On the FEL side: Harmonic

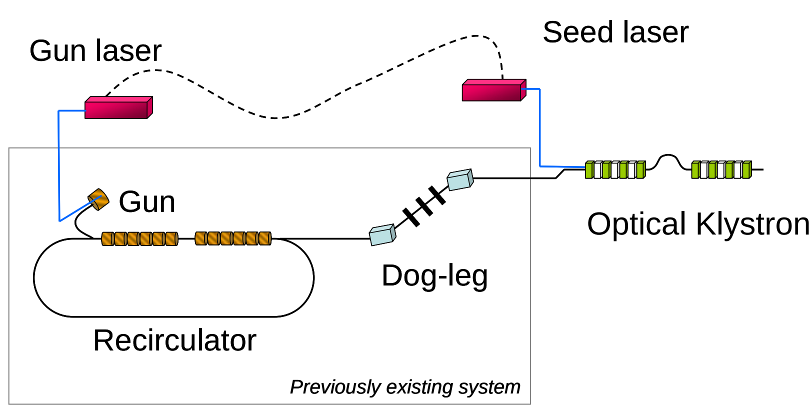

Fig 1. Overview of the accelerator systems and test FEL.

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Generation, laser systems, control of overlap of the optical mode to electron beam focus, modelling, simulations and beam handling.

BASIC LAYOUT & COMPONENTS

The layout out the system is shown in fig 1.

The accelerator system

The accelerator for the FEL test facility utilises the injector system [3] for the storage rings at MAX-lab. These facilities are available during the majority of time as injections are only scheduled for a few instances a day.

The system is built around two 5.2 m long linac structures. These are equipped with SLED cavities [3] and powered by one 35 MW klystron each, thus being able to provide up to 125 MeV each. The electron beam is passed via a recirculation system through the linacs twice and thus reach routinely an energy of 400 MeV. (The design value is 500 MeV.)

The electron source is a RF-gun [4] consisting of ½+½1 cells. The cathode is BaO and is used in two modes. Either as a thermionic source operated at 900 C, mainly aimed for storage ring injection, and in a gated mode with a 5 ns laser to be able to fill bucket-by-bucket into the storage rings. In the latter mode the cathode temperature is reduced just below thermal emission, around 600 C, and the electrons are gated by the laser system.

For the FEL operation the temperature will be reduced further and a more powerful laser system providing 10 ps pulses will generate the electrons.

The electron gun provides 2 MeV and the beam is passed through a magnetic energy filter bending 120 degrees before entering the linac system.

The transport system from the linac to the FEL is the one used for injections into the MAX II storage ring. It consists of mainly a dog-leg moving the beam from the basement up to ground floor level. This dog-leg has proven a good solution for bunch compression.

Table1: 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

The optical klystron

The optical klystron is built around two re-used undulator structures. 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 devices have been re-measured, re-shimmed and equipped with new carriages [5]. The chicane system is a newly constructed system. The parameters are summarized in table 1.

Laser system and transport optics

A combined laser system for the gun and the seeding of the HG-FEL has been purchased from Thales SA. The system comprises a common oscillator system locked to the RF of the accelerators to better than 1 ps and synchronization by optical fibre. The gun laser branch consists of a pulse shaper, amplifier and harmonic generation. The seed laser system is similar, but without the pulse shaper. The layout of the system is shown in fig 2.

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.

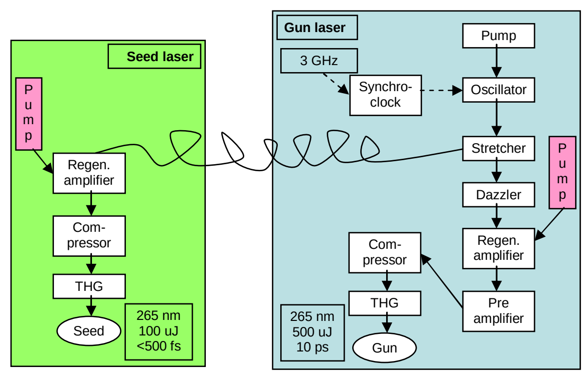

Fig 2. The laser system

Diagnostics

The start up of the system will mainly rely on OTR screens for alignment and beam diagnostics. A calibrated current monitor will be installed, but the response is not in the range of the short pulses accelerated. Beamloss monitors [6] are already installed along the undulators, which will allow a rough estimate of beam position. Energy distribution will be available on a screen at a dispersion point by the beam dump. Alignment of the laser beam to the electron beam will be made by optical methods using the spontaneous emission in the modulator undulator and the laser beam. Temporal overlap between seed laser and electron bunch will be achieved by several techniques: photodiodes for the >ps range, detecting the THz signal from the fraction of the electron bunch interacting with the seed laser [6], detecting increased energy, spread due to seed laser, at the beam dump.

Emittance measurements will be done by quadrupole scans and 1-to-1 imaging of an OTR screen signal. Bunch length measurements will be done both with CTR pulses measured in a Michelson interferometer [7] and by electro-optical techniques using the seed laser as probe pulse [8].

TARGET PERFORMANCE

The performance of the system in the first phase has been calculated. The basic operation has been established in the injector, but the performance outlined below has not been verified in detail.

final acceleration which increases the final energy spread, but possibly reduces the timing jitter. An achromatic dogleg consisting of two 15 degree bends with 5 quadrupoles in between performs the compression. The dogleg provides an R56 of 5.5 cm which gives maximum compression for an accelerating linac RF phase of 30 deg. This however leads to a very high energy spread (since compression happens after full acceleration). After

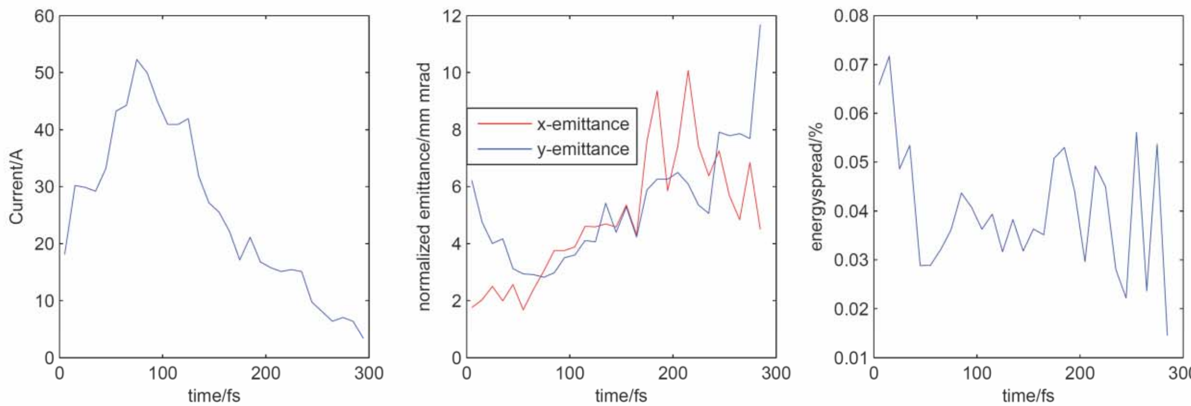

Fig 3. Simulations of the beam performance from the current gun system at the entrance to the optical klystron.

Electron beam

The electron beam is extracted from an RF gun delivering around 2 MeV. In normal thermionic mode there is a strong bunching right at the cathode surface. As the energy is low the space charge effects significantly increase the emittance. By gating at a later phase angle the effect is reduced. For the FEL tests it will be used as a photocathode gated gun. The gun laser will provide a 10 ps pulse which can be tuned to an optimal phase, around 30 degrees, to reduce space charge effects. The gun structure though was not optimised for low emittance operations and thus the extracted charge has to be reducedto ~0.1 nC to meet the demands of FEL tests.

The electrons are then accelerated in the recircuclated linac system to >400 MeV. Compression is done after optimizing the accelerating phase to give maximum peak current while maintaining low emittance and energy spread it was found that 8 deg gives the best electron properties.

The beam has been traced through the system using the codes Parmela [9], ASTRA [10] and elegant [11]. At the entrance of the optical klystron a peak current of 50 A, a normalised emittance around 3.5 mm mRad and an energy spread of 0.04% can be achieved in a time window of 300 fs (fig 3). The total charge in the window defined by the seed laser (time and transverse dimensions) is only 0.01 nC. The pulse has a long tail with lower current which will not interact with the seed laser.

The pulse is stable in tracking and the peak current is matched in time to the lowest emittance and energy spread.

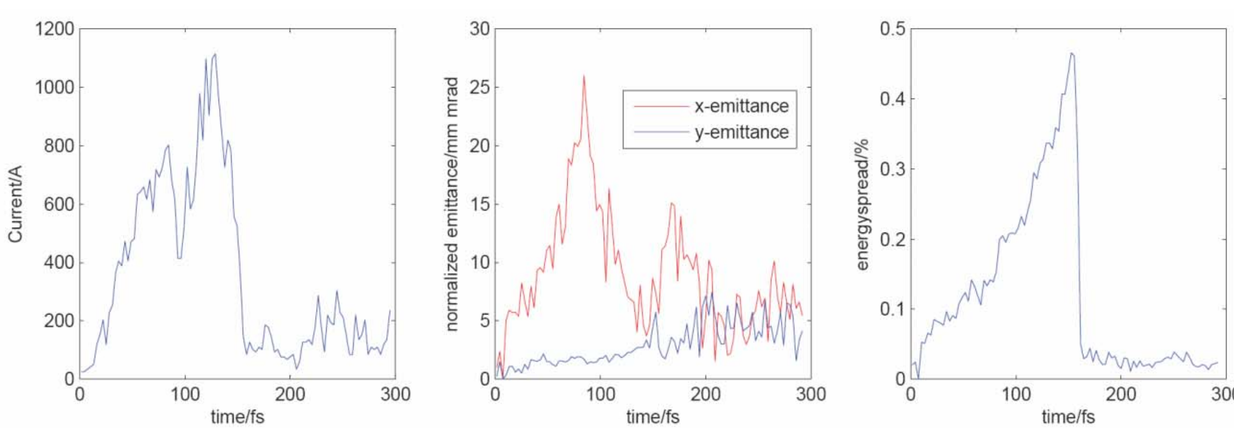

Fig 4. The beam at the optical klystron entrance in improved mode with a new gun. (not optimised results)

Coherent output

The coherent enhancement and the sensitivity to emittance and energy spread have been calculated by a 1D model. In the 300 fs seed-laser-window the power is 0.2 MW (60 nJ) in the third harmonic at 88 nm. The coherent enhancement is $6*10^4$ over the incoherent emission in the window. The total incoherent pulse should have an energy of 6 pJ. A 1D model should in this context be regarded as an "optimum performance".

To increase the power an improved gun structure has been designed.

STATUS

The project is at the moment (summer 2007) developing quickly with the goal of taking the phase 1 into operation in the fall 2007.

Parts in operation

The complete injector and electron beam transport system are in operation. The electron gun is operating in both thermionic mode and in laser gated mode with a long pulse, 5 ns, laser system. The undulator systems are installed and in operation.

Parts installed

The laser systems are being installed/are installed. Laser beam transport and optics will be installed after laser system acceptance tests. The magnetic and vacuum system around the undulators are being installed at the moment. Basic diagnostic systems are currently being installed.

DEVELOPMENT OF THE SYSTEM

The system is planned to be developed in two new phases.

Phase 2 New gun

The second phase contains a new electron gun [12] allowing operation at higher bunch charges while retaining the emittance. This system is an adapted BNL/SLAC type RF gun with an emittance compensating solenoid system [13].

The simulations of the beam performance with the new gun system can be found in fig 4. The current at a maintained emittance is considerably increased allowing for higher output power. The compression of the bunch is trickier in this high charge case and the energy spread tends to increase. In start-to-end simulations it can be seen that the HG-process chooses to operate at a part of the bunch where the current is not the maximum but the energy spread is slightly lower. In the third harmonic at 88 nm a power of 11 MW in < 100 fs is shown and at the 5th harmonic at 53 nm 1.4 MW is shown. The results shown here are not the final optimisations (which await publication).

Phase 3 HHG source

The third phase will use a HHG (High Harmonic Generation) chamber on the seed laser system to seed the FEL process at a lower wavelength down to 100 nm. The drive laser for the seed pulse will be equipped with an additional amplifier and a High Harmonic Generation gas jet chamber. This chamber can provide a tunable seed pulse down to 30 nm range. The electron energy will though limit shortest seeding wavelength in the modulator undulator to around 100 nm.

The gas jet chamber is system is developed and in operation at the Lund Laser Center [14] and an adapted chamber system will be built for the seeding. This part of the project still awaits funding.

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