SEEDING OF THE TEST-FEL AT MAX-LAB

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Abstract

The installation of the test FEL at MAX-lab has recently been completed. The system will be seeded by a tripled Ti:Sapphire laser (263 nm) synchronized to the RF system and the gun laser. Issues important for the seeding will be presented, ranging from the laser system via the layout of photon and electron optics to timing/synchronization and the theoretical approach.

INTRODUCTION

This article is mostly concerned with seed laser, a major part of the test-FEL in Lund [1][2]. Schematics of the FEL at MAX-lab with most important parts are shown in Fig 1 (without lasers whose beams are just shown with arrows).

The gun laser provides an optical pulse (10 Hz, 10 ps, 263 nm, 200 μJ), which hits the BaO cathode inside the gun and produces a single bunch. The electron bunch (2 MeV) then travels through an energy filter into the linac. It passes the two linacs twice and gets an energy of about 400 MeV. After the recirculator it comes out through a “dog-leg” used to compress the pulse. It enters the half-chicane (where seed laser beam is added) and continues to the modulator undulators [3].

The half-chicane consists of two bending magnets which lift the electron beam by about 20 mm to allow the seed laser beam to enter the vacuum system and go along the same path. The seed lasers role is to provide a laser pulse (263 nm, 350 fs, 10 Hz, ~100 μJ) that will be used inside the modulator (30 periods, period length 4.8 cm) to modulate electron energy in the electron bunch. The chicane after the modulator consists of four dipole magnets. The chicane introduces bunching in the electron bunch whose energy was modulated in the modulator. The seed laser pulse is stopped in the chicane to prevent flooding of detectors.

The electron bunch continues to the radiator (30 periods, period length 5.6 cm), and later to the dump magnet where the electrons are separated from the produced light.

LASER SYSTEM

The lasers (ordered from THALES Laser) are placed in separate temperature controlled hutches. Gun laser hutch is close to the linac. The seed laser hutch is placed inside the MAX-II ring next to the undulators.

The 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 oscillator is common for both the seed and the gun laser. The pulses of the oscillator are stretched and then sent through an elliptical core polarization maintaining optical fiber 90 meters to the seed hutch. The bandwidth of the pulses exiting the fiber is about 5 nm. The pulses seed a regenerative amplifier which is pumped by a doubled Nd:YAG laser with 10 Hz repetition rate (30 mJ are used for pumping).
After amplification the pulse is compressed to around 350 fs, tripled to 263 nm (~100 μJ) and lead through the focusing system (lenses L1 and L2 in Fig. 2 with focal lengths of -75 cm and +200 cm respectively) onto the dielectric mirror D1. The position of L2 can be controlled by a micrometer screw to adjust focus of the laser beam to be inside the modulator. After D1, the laser beam co-propagates with an alignment laser (Laserglow 532nm 20mW) so all the following mirrors are metal (Al, final throughput ~50%). A delay stage (Thorlabs 150mm delay stage mounted on a non-motorized stage 1m long) allows more precise timing of the seed laser pulse relative to the electron bunch. The pulse then leaves the laser hutch onto two movable mirrors (MM2 and MM1 in Fig 2), and onto the final (fixed) mirror which is inside the vacuum system. The distance from the exit of the laser hutch to the middle of the modulator is about 6.4 meters (optical path).

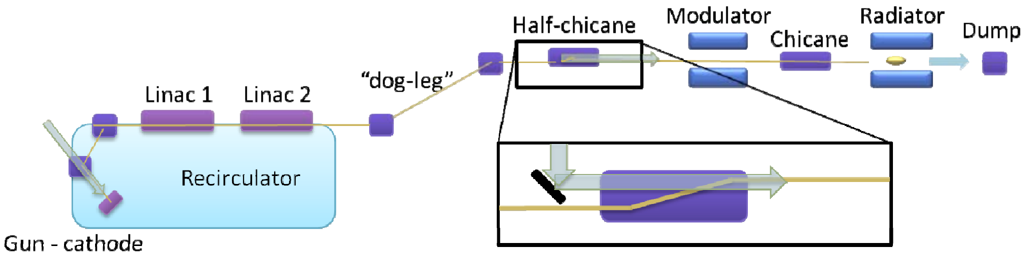

Figure 1: Layout of the MAX-lab test-FEL. Laser pulses from the gun and the seed laser are shown as arrows. An electron bunch is accelerated to 400 MeV and seeded with femtosecond laser in the modulator. The system is expected to produce radiation at 263 nm and its harmonics.

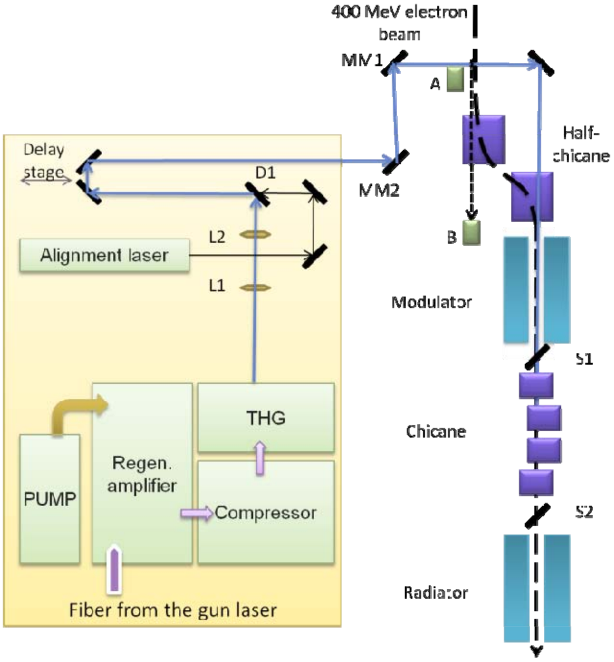

Figure 2: Seed laser layout and optics to focus the laser beam into the modulator. Laser beams are presented with full arrows. The electron beam is presented with dashed/dotted line (depending on whether the half-chicane is on or off). L1 and L2 are lenses for focusing of the laser beam inside modulator. A and B are diodes used for time synchronization. MM1 and MM2 are movable mirrors. S1 and S2 are screens used for alignment (see text).

ALIGNMENT

The time difference between two pulses coming from the oscillator is about 10.7 ns. By setting time delays inside the regenerative amplifier different pulse from the oscillator can be selected for amplification. This allows time shifts of the seed laser pulse in steps of 10 ns. Considering the seed laser bunch length (350 fs) and the electron bunch length (less than 1ps), it is obvious that synchronization still remains challenging. To get close (into the range of the motorized delay stage) two fast Si PIN photo diodes are connected to a 5 GHz oscilloscope (LeCroy WaveMaster 8500). In Fig. 2 they are marked as A and B. The distance between them is measured so the time difference is known. That time difference is compensated by a longer cable on the diode A so that both signals are captured on the same sweep. Diode B is monitoring the arrival time of electrons, and diode A of the laser pulse. Both diodes are placed outside the vacuum system, so diode B is actually looking at the radiation shower created when the electron bunch hits the vacuum chamber, and that happens when the magnets on the half-chicane are turned off. That situation is shown with dotted line in Fig 2. With the diodes it is possible to go lower than 500 ps in synchronization since they have a very fast rise time (see Fig 3). The precision is sufficient then for a manual search of temporal overlap using the delay stage.

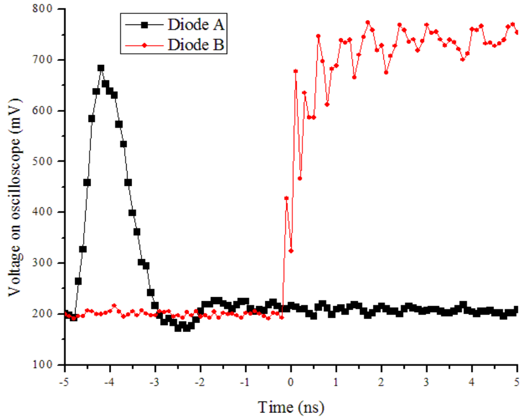

Figure 3: Signal from two diodes used for synchronization of the seed laser pulse and the electron pulse. Both diodes are monitoring electron bunch arrival in this case for calibration purposes. The fast rise time allows resolution well below 500 ps.

Stretching of the seed laser pulse to 1ps and weaker focusing (1.5 mm waist) is planned to make overlapping (longitudinally and transversely) easier. Preliminary time-dependent simulations performed using GENESIS 1.3 [4] show that the induced energy spread (see Fig 4) is still sufficient to generate the third harmonic (88 nm) of the seed laser in the radiator.

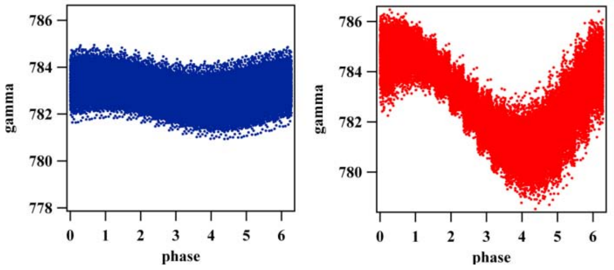

Figure 4: Left image shows the phase space after the modulator in case of longer seed laser pulse (50 MW, 1 ps) and with weak focusing (1.5 mm waist) Right image shows the phase space in the “ideal case” (200 MW, 300 fs, 0.5 mm waist).

S1 and S2 in the Fig 2 represent screens in front of which YAG crystals were placed to induce fluorescence. Those two screens are used for transversal alignment of the laser with the electron beam. There are similar screens after the radiator, and one of them is used for alignment of the seed laser with the alignment laser. It is checked inside the laser hutch that the alignment laser and the seed laser match.

FURTHER IMPROVEMENTS

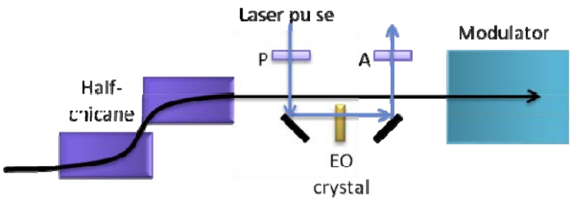

Figure 5: Schematics of the planned electro-optical technique to synchronize the seed laser pulse and electron bunch more precisely.

One way to improve synchronization of the pulses is to use electro-optical techniques [5][6]. A chamber with ZnTe and GaP crystals to perform electro-optical measurements is planned. The goal is to get to picosecond range in synchronization precision. In Fig 5, the planned position of the chamber with crystals is shown. An infrared laser pulse extracted before the tripling in the seed laser is polarized and sent through a crystal in which birefringence is induced by the passing electron bunch. The change of polarization is later analyzed.

Another field in which improvements are expected is seeding with laser generated harmonics. Preliminary tests with generating powerful enough harmonics will be done at Lund Laser Center during this summer.

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