EXPERIENCE WITH THE PHOTOINJECTOR LASER AT FLASH

S. Schreiber,*, M. Görler, K. Klose, M. Staack, L. Fröhlich, DESY, Hamburg, Germany
I. Will, I. Templin, MBI, Berlin, Germany

Abstract

The photoinjector laser system of FLASH is a key element for the generation of high quality electron beams required for a stable and reliable operation of the facility. FLASH is the VUV and soft X-ray FEL user facility at DESY. FLASH is based on superconducting accelerating structures allowing to accelerate electron bunch trains of a length of up to 800 μs with a repetition rate of 10 Hz. Based on the standard 1 MHz pattern, the laser provides to some extend a flexible bunch train structure. We report on operational issues and on the performance of the laser system and its integration into the machine protection system.

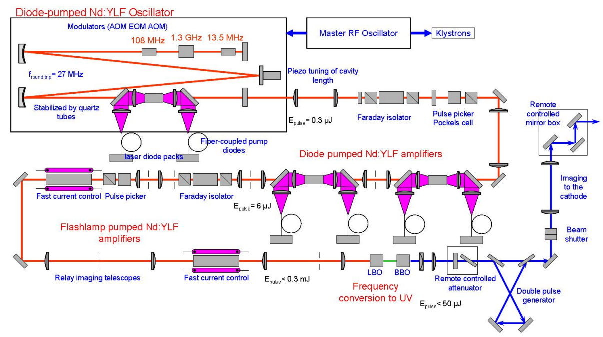

Figure 1: Schematic overview of the laser system.

INTRODUCTION

FLASH is a free electron laser user facility at DESY providing laser-like radiation from the VUV to the soft X-ray wavelength regime.[1, 2] SASE free electron lasers require an excellent beam quality, which is achieved with an injector based on a laser driven rf gun.[3] The electron beam is accelerated with TESLA superconducting modules.

A high quantum efficiency photocathode [4] together with a synchronized mode-locked laser system is used to generate the electron beam structure typical for superconducting accelerators: some thousand bunches in a millisecond long rf pulse. High quantum efficiency cathodes allow to use a laser system with moderate average power in the Watt range.

The user facility FLASH has been realized by upgrading the TESLA Test Facility (TTF) phase 1 FEL to phase 2.[5] The TTF phase 1 laser system [6] has also been upgraded to a partially diode pumped system as described in [7].

In this report we describe the running experience with the laser system and its integration into the machine protection system of FLASH.

OVERVIEW OF THE LASER BASED ELECTRON SOURCE

The FLASH electron source is based on a laser driven L-band 1+1/2-cell rf gun operated with a 5 MW 1.3 GHz klystron. The rf pulse length is up to 900 μs, the repetition rate 5 Hz, up to 10 Hz are possible.

The electron beam is generated by photoemission with a Cs_2Te photocathode. With a forward rf power of 3.2 MW a gradient of 42 MV/m on the cathode surface is achieved on crest. High gradient on the cathode surface is required to preserve excellent beam quality. The cathode exhibit a high quantum efficiency in the range between 1 and 5 % for UV laser light. The charge per bunch required is 1 nC which translates into a laser pulse energy of not more then 0.5 μJ per pulse. The design of the laser accounted for a QE of 0.5 % only, a bunch frequency of 9 MHz within the train and an overhead by a factor of 4. With a conversion efficiency of 15 % from the IR to UV this asks for an average power of 2 W in the infrared.

THE LASER SYSTEM

The laser design is based on a pulsed master oscillator with subsequent amplification stages. Details of the system layout are described in [7], a schematic overview shows Fig. 1.

The laser material chosen is Nd:YLF, lasing at a wavelength of 1047 nm. The material has together with a high gain a long upper-state lifetime of 480 μs, and exhibits only a weak thermal lensing. This makes it suitable to produce pulse trains with milliseconds length. The oscillator and preamplifers are end-pumped with laser diodes emitting at 805 nm with a maximum power of 32 W. The two main amplifiers are flashlamp pumped.

The Pulse Train Oscillator

The pulse train oscillator (PTO) runs at 27 MHz synchronized to the master rf of the accelerator. It is a pulsed osciallator with the advantage of a much higher single pulse energy of 300 nJ as compared to typical cw oscillators. The master provides reference rf signals in the frequency of the accelerator of 1.3 GHz and its harmonics 108, 27, and 9 MHz. The synchronization to the rf is achieved using two

* siegfried.schreiber@desy.de

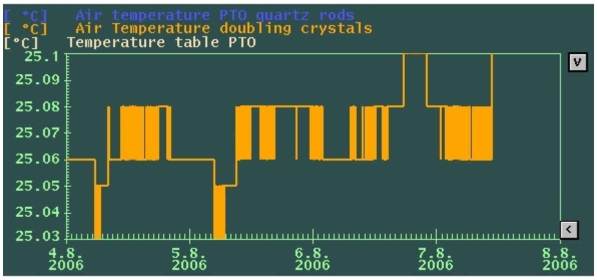

Figure 2: As an example, the air temperature measured at the laser over a period of 3 days. The temperature reading is within ±0.02°C.

acousto-optic modulators running at 27/2 = 13.5 MHz and 108 MHz resp., and an additional electro-optic modulator powered with the amplified 1.3 GHz reference. The latter provides synchronization to the required 1 ps level. The oscillator length is stabilized against temperature drifts with two quartz rods. Quartz has a low temperature coefficient of expansion of $0.6 \cdot 10^{-6}$ m/°C. At the same time, the temperature of the laser room is stabilized to ±0.02 °C (Fig. 2). Both measures provide the bases for an excellent phase stabilization of the laser pulses with respect to the rf. An active fast feedback loop could be omitted, only a slow feedback acting on the resonator length is implemented.

The phase jitter of the laser pulses in respect to the rf can be estimated using the phase scan technique. The phase stability measured with this technique depends also on the performance of the gun rf amplitude and phase regulation system and therefore only gives an upper limit. The measurement results an rms phase jitter of 0.14 °in respect to 1.3 GHz rf.[8] This translates in an timing stability of the laser pulses of better than 300 fs rms.

Amplification

Selected pulses of the 27 MHz output of the PTO is amplified with a chain of linear amplifiers, also based on Nd:YLF, diode and flashlamp pumped.

A Pockels cell based pulse picker before amplification runs at 1 MHz forming a pulse train with a length of 1.5 ms. With the present high voltage driver (4 kV), up to 3 MHz is possible. The train is amplified by two diode pumped single pass amplifiers from 0.3 to 6 μJ per micro pulse.

A second pulse picker before the last amplification stage has two functions. The diode pumped amplifiers produce a transient at the beginning of the pulse train. The second pulse picker choses the flat part of the train. The second aim is to give the operator or user of the laser the possibility to remote control the number of pulses and to a certain extend the bunch pattern. Details will be described later in this report.

The final amplification to 300 μJ per pulse is performed by two flashlamp pumped amplifiers. They have already been used at the phase 1 laser system. They provide a power over the pulse train of about 300 W or an average power of up to 3 W for 10 Hz repetition rate.

The pump diode lasers are running since their installation for more than 20.000 h without any visible degradation. The flashlamp life time is between 1 to $5 \cdot 10^{7}$ shots and are routinely replaced every 40 days.

The infrared radiation (1047 nm) is doubled twice with an LBO and a BBO crystal to the UV (262 nm). The energy stability of a single micro pulse is between 1 and 2 % rms. However, to maintain this stability, a frequent fine tuning of the BBO phase matching angle is required.

Transport Beamline

A variable attenuator consisting out of a Brewster angle polarizer together with a remotely rotatable half wave plate. It allows to adjust the laser pulse energy according to the electron beam charge required. It is also used for a slow charge feedback to compensate slow drifts in electron charge.

Spent beams at various locations (PTO, Pockels cell, LBO, attenuator) are measured with fast photodiodes and recorded with a 1 MHz ADC giving additional information to the operator.

A double pulse generator can be switched into the beamline doubling each micro pulse with a variable distance of some nanoseconds in order to accelerate double bunches in close-by rf buckets. Refer to [9] for details.

In addition, the laser beam can be directed remotely to a joulemeter to measure its energy. It is frequently used for quantum efficiency measurements. The laser pulse can also be directed to a fast streak camera (Hamamatsu FESCA 200) to measure its longitudinal pulse structure. The pulse length in the UV is measured frequently and is stable at 4.4±0.1 ps sigma.

The UV beam is transported from the laser hut to the rf gun. The beamline has a length of 10 m. It is protected with tubes against dust and air turbulences. The beamline needs five dielectric mirrors with a coating optimized for 262 nm. A remote controlled mirror box allows true linear steering of the beam along the cathode. The last mirror in the vacuum chamber guides the beam to the cathode. It is manufactured of solid aluminum. Its surface is diamond turned and has a good optical flatness and a reasonable reflectivity of 90 %. We have chosen a solid metal mirror for two reasons. Dielectric mirrors charge up when hit by darkcurrent. Charging and discharging leads to cracks on the mirror surface and influences the electron beam trajectory. Secondly, experiments supported by simulations have shown, that the beam emittance is also effected.[10]

The laser beam transport is based on the relay imaging technique together with spatial filtering. A hard edge aperture downstream of the diode pumped amplifiers is consecutively imaged to the flashlamp pumped laser heads, to the doubling crystals and finally to the cathode. This results in a quasi flat laser pulse on the cathode which is further sharpened by a hard edge iris aperture close to the gun. The magnification of the telescope system is about 10 re-

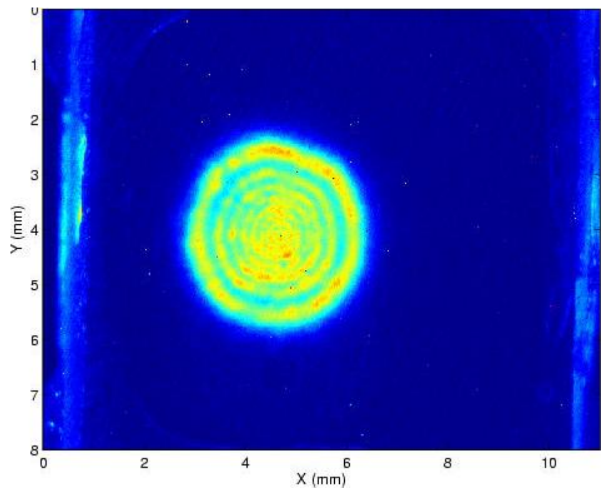

Figure 3: Laser beam profile measured with a Ce:YAG crystal at the 'virtual cathode'. A large laser spot (diameter 1 to 1.5 cm) is seen through an iris of 3 mm in diameter. Although interference fringes show up, the pointing stability is much improved.

Table 1: Laser parameters. Most parameters are adjustable and are set according to the requirements for the specific experiment.

parameter	value
laser material	Nd:YLF
wavelength after conversion	262 nm
output structure	pulsed trains
train repetition rate	5 or 10 Hz
train length	up to 800 μs *
micro pulse spacing	0.33 us to 800 μs *
micro pulse longitudinal shape	gaussian
micro pulse length	4.4$\pm$0.1 ps (sigma)
transverse profile	flat, with fringes
transverse size on cathode	3 mm diam.*
	*adjustable

sulting in a large beam size of about 1 cm in diameter. The iris is remote controlled and is usually adjusted to a diameter of 3 mm cutting a large portion of the laser beam. This results in a roughly flat transverse profile. In addition and most important, these measures reduce the pointing jitter by a large amount and contributes to the stability of the electron source. However, interference fringes created by the hard edge aperture could not been completely avoided. The modulation is about 20 %. An upgrade is foreseen to reduce the modulation (see [11]).

A so called virtual cathode is used to set-up and control the transverse laser beam shape. A remote controlled mirror directs the laser beam onto a Ce:YAG crystal mounted at a distance identical to the cathode position. Figure 3 shows an image of the laser beam on the virtual cathode.

Table 1 summarizes the main laser parameters.

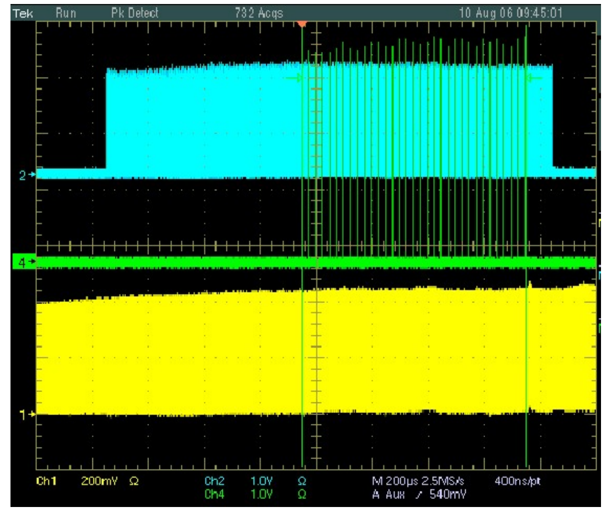

Figure 4: Scope screen shot of a 40 kHz pulse train (green trace, Nb. 4). In addition, the central part of the 27 MHz train of the oscillator (PTO) (yellow, nb 1), and the 1 MHz pulse train after the diode pumped preamplifiers (cyan, nb. 2) are shown.

BUNCH TRAIN PATTERN AND MACHINE PROTECTION

Experiments with FEL radiation often require different electron bunch train pattern. The laser can provide to a certain extend a flexible bunch train pattern chosen by the operator.

We use the Pockels cell based pulse pickers to vary the pattern of the laser pulse train. The Pockels cells may run for 1.5 ms with a rate of up to 3 MHz, pulsed with up to 10 Hz.

An FPGA based controller has been developed. It takes as an input the 9 MHz rf signal from the master oscillator and the 5 Hz or 10 Hz trigger from the control system. The controller produces the trigger gates which go to the Pockels cell drivers. The FPGA allows a flexible control on the number of pulses and the repetition rate, for example in addition to the standard 1 MHz, 250 kHz, 100 kHz, 10 kHz, and others are possible. As an example, Fig. 4 shows a scope screen shot of a 40 kHz pulse train.

The controller also serves as an interface to the machine protection system (MPS).[12] Three beam modes are defined: a single pulse, short pulse, and a long pulse mode. These modes are a machine safety measure, for instance only single bunches are allowed when screens are inserted in the high energy part of the accelerator. Depending on the mode, the controller limits the number of laser pulses picked by the second Pockels cell, independent of the operator request. It also receives a fast beam stop signal from the MPS, for instance when losses grow within a pulse train. The stop signal suppresses further triggers to the pulse pickers. The reaction is immediate within some tens of nanoseconds.

For a safe operation of the laser, important operating conditions are surveyed by an SPS based system. For instance, the system issues warnings and interlocks on overtemperature, water flow interruptions and so on. The overall system is controlled with a VME-crate based cpu integrated into the FLASH control system providing an interface to the operators. The cpu reads important laser parameters and drives for instance flashlamps, slow feedbacks on a shot to shot bases.

CONCLUSION

The photoinjector laser system has been upgraded by partially replacing flashlamp pumped laser heads by diode pumped heads. The upgraded system has been put into operation at FLASH in February 2004 and providing beam since then (for more than 20.000 h). The stability and reliability of the system is satisfactory, maintenance a routine task. An FPGA based controller allows to drive the pulse pickers with a variable pulse pattern and serves at the same time as an interface to the machine protection system. The laser is integrated into the FLASH control system providing informations about the status of the system and various remote control options.

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REFERENCES

[1] V. Ayvazian *et al.*, Eur. Phys. J. **D 37**, 297 (2006).

[2] S. Schreiber, "First lasing at 32-nm of the VUV-FEL at DESY," eConf **C0508213**, MOOB002 (2005), *Presented at the 27th International Free Electron Laser Conference (FEL 2005), Stanford, California, 22-26 August 2005.*

[3] S. Schreiber, eConf **C0508213** (2005) THPP038 [arXiv:/] *Presented at the 27th International Free Electron Laser Conference (FEL 2005), Stanford, California, 22-26 August 2005.*

[4] D. Sertore, P. Michelato, L. Monaco, A. Bonucci, J. H. Han and S. Schreiber, PAC-2005-MOPB009 *Prepared for Particle Accelerator Conference (PAC 05), Knoxville, Tennessee, 16-20 May 2005.*

[5] "SASE FEL at the TESLA Facility, Phase 2," DESY-TESLA-FEL-2002-01.

[6] S. Schreiber, D. Sertore, I. Will, A. Liero and W. Sandner, Nucl. Instrum. Meth. A **445** (2000) 427.

[7] I. Will, G. Koss and I. Templin, Nucl. Instrum. Meth. A **541** (2005) 467.

[8] E. Vogel, W. Koprek, P. Pucyk, EPAC-2006-TUPCH189, Proceedings of EPAC 2006, Edinburgh, UK, 26-30 June 2006.

[9] O. Grimm, K. Klose and S. Schreiber, EPAC-2006-THPCH150, Proceedings of EPAC 2006, Edinburgh, UK, 26-30 June 2006.

[10] M. Krasilnikov *et al.*, DESY-M-04-03U *Prepared for 9th European Particle Accelerator Conference (EPAC 2004), Lucerne, Switzerland, 5-9 Jul 2004.*

[11] M. V. Hartrott *et al.*, eConf **C0508213** (2005) MOPP034 [arXiv:/] *Presented at the 27th International Free Electron Laser Conference (FEL 2005), Stanford, California, 22-26 August 2005.*

[12] L. Fröhlich *et al.*, "First Experience with the Machine Protections System of FLASH", FEL-2006-THPPH016, these proceedings.