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Nuclear Instruments and Methods in Physics Research A 445 (2000) 427–431

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Running experience with the laser system for the RF gun based injector at the TESLA Test Facility linac

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Abstract

During the run 1998/1999, the new injector based on a laser driven RF gun was brought into operation at the TESLA Test Facility Linac (TTFL) at DESY. A key element of the injector is the laser system to illuminate the RF gun cathode to produce short (ps) electron bunches of high charge (nC). This electron beam is used to perform various experiments for the future TESLA linear collider, and to drive the free electron laser TTF-FEL. The laser design is challenged by the unusual requirement of providing synchronized ps UV pulses in 0.8 ms long trains with ambitious stability requirements. The design was also driven by the requirement to have an operational system with a high reliability. The system is based on a mode locked solid-state (Nd:YLF) pulse train oscillator followed by a linear amplifier chain. In a first phase, a laser pulse rate of 1 MHz within the train has been realized, 2.25 MHz and 9 are in preparation. Performance and running experiences with the laser system during the last TTF run are reported.

PACS: 42.55.P, R; 42.60.F; 85.60.H; 42.60.R; 41.60.C

Keywords: Solid-state lasers; Mode locking; Long pulse laser operation; Photoinjector; Photocathode; Free electron laser

1. Introduction

The TESLA Test Facility Linac (TTFL) [1] under operation at DESY uses an RF photoinjector together with a superconducting linac to generate and accelerate an electron beam adequate for the proof-of-principle experiment of the TTF free electron laser (TTF-FEL) [2]. The laser system driving the RF gun is a key element, which determines significantly the quality of most beam parameters, and thus plays a major role in the success of the free electron laser.

Superconducting accelerating structures allow high duty cycles, in the case of TTF 0.8 ms long RF pulses with a repetition rate of 10 Hz. To make use of this, the laser system is challenged by the generation of ms long pulse trains. Since this is an unusual requirement for common laser systems, the development of novel techniques were required to accomplish this task. Another basic guideline for the design was to realize a robust and reliable system, which fulfills the specified performances routinely during normal running conditions of an FEL user

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0168-9002/00/$ - see front matter
PII: S0168-9002(00)00096-6

facility. Independently, a second laser system for similar purposes has been built and is in operation at the A0 gun test beamline at Fermilab [3].

During the last TTF run from December 1998 to March 1999 the laser system has been continuously operated allowing to evaluate its reliability under realistic conditions. In the following, principle components of the laser system will be described, results of its performance are given followed by a discussion of the overall experience with the system during the run.

2. Description of the laser system

Table 1 gives an overview on the specified parameters of the laser system, Fig. 1 shows an overview of the laser components. A complete description is given in Ref. [4].

The main difficulty is to produce a flat and stable train of 800 UV pulses within 0.8 ms, each with an energy of at least 5 μJ. The pulses have to be synchronized within 1 ps with the RF system driving the gun and the linac klystrons. To meet both requirements, an active mode locked pulse train oscillator (PTO) based on Nd:YLF at a wavelength of 1047 nm was developed. One difference to common oscillators is, that the PTO already amplifies the pulse train to several 10th of W within the train (typically 30 W), which avoids the use of a regenerative amplifier. Mode locking is established by an acousto-optic mode locker driven by a 27 MHz RF signal provided by the TTF master RF oscillator [5]. All relevant RF signals required for linac operation are derived directly from the master oscillator to assure good phase stability between the RF signals. An analog feedback system is used to lock the oscillator to the reference phase. This is done with an additional electro-optic mode locker driven with 1.3 GHz with which a phase stability of better than 0.5° or 1 ps is achieved. The PTO is operated in a pulsed mode pumped with flashlamps. About 1 ms is sufficient for stabilization (see Fig. 2).

Prior to the amplification process, the 54 MHz pulse train output of the PTO is reduced to the desired train length and number of pulses in the train using a Pockels cell together with a polarizer. For most of the TTF experiments, 1 MHz repetition rate is chosen, were the number of pulses is adjustable from 1 to 800. For future FEL experiments, 2.25 and 9 MHz trains are in preparation.

The amplification to 200 μJ per pulse (thus about 200 mJ per train), is done in a linear single pass amplifier chain. Three amplifiers with an adjustable gain in the order of 10 are sufficient. A novel feature is the use of programmable power supplies. The flashlamp current is set in steps of 10 μs width in predefined feedforward tables. This is essential to obtain a flat pulse train and gives in

Table 1
Basic specifications of the TTF laser system. They are compared to the measured performance during the last run

Item	Specification	Measured
Pulse train	800 pulses spaced by 1 μs	Achieved
Repetition rate	10 Hz	Achieved, run mode 1 Hz
Pulse energy	5 μJ (262 nm)	50 μJ (262 nm)
Pulse length (262 nm)	2–10 ps (sigma)	7.1 ± 0.6 ps (sigma)
Transverse profile	Flat-top	Achieved
Flat-top homogeneity	$\pm 10\%$	Partially achieved
Energy stability	Peak–peak	
Train to train	$\leq \pm 10\%$	$\leq \pm 5\%$
Pulse to pulse	$\leq \pm 10\%$	$\leq \pm 5\%$
Synchronization	To reference RF signals	Achieved
Phase stability	≤ 1 ps rms	≤ 1 ps rms

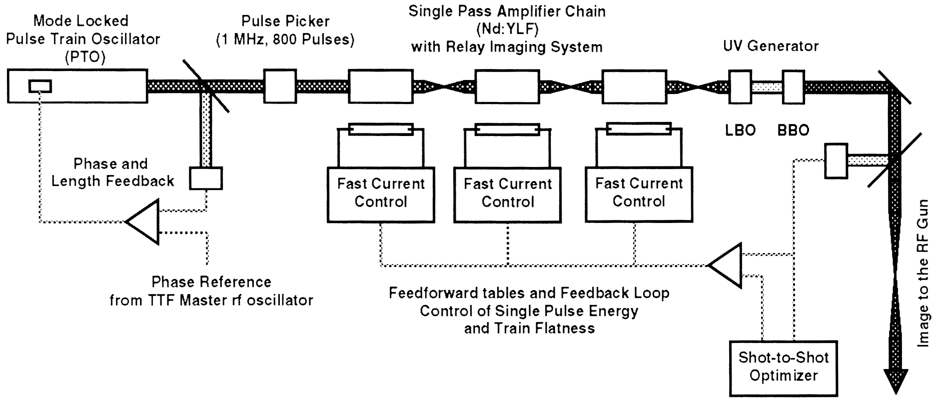

Fig. 1. Schematic overview of the TTF photoinjector laser system.

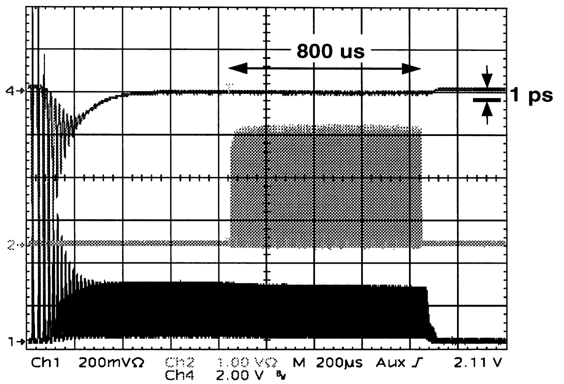

Fig. 2. Oscilloscope trace of the output of the pulse train oscillator (PTO) (trace 1), the phase of the pulses relative to the reference (trace 4), and the pulse train after amplification measured in the green with a fast photodiode (trace 2). Note, that due to the scale (200 μs per div.) individual pulses in the train are not visible. Indicated is the vertical scale of the phase signal corresponding to a phase shift of 0.5° of 1.3 GHz, which corresponds to 1 ps.

addition the opportunity for an efficient amplitude feedback system [6].

Since the work function of the Cs_2Te cathode used in the RF gun reaches its maximum at 5 eV [7], the fundamental wavelength has to be converted into the UV. With the two non-linear crystals LBO and BBO a conversion efficiency to 262 nm of 15–20% is achieved. The energy of a UV pulse can be adjusted in a wide range up to 50 μJ, largely sufficient to produce 8 nC electron bunches even with a moderate quantum efficiency of the cathode of 0.5%.

A relay imaging system generating near flat-top pulses contributes to the homogeneous amplification along the train. A hard edge aperture at the exit of the PTO is relay imaged together with spatial filtering to each amplifier, the frequency conversion stage, and the cathode of the RF-gun. Imaging onto the cathode has also the advantage of a much better pointing stability on the 10 m transfer beamline from the laser to the RF-gun. The laser system is installed in a separate room inside the TTF experimental hall. Air conditioning provides a stable temperature of $\pm 0.5°C$. No beam jitter has been observed using a CCD camera near the gun, the pointing jitter is less than 2 μrad. The imaging is done using a telescope with a magnification of 1 to transport the beam into the linac tunnel. A second telescope with a magnification of 10 images the beam onto the cathode. For 8 nC operation, a laser beam diameter of 10 mm is used, for 1 nC operation it is reduced to 3 mm. The mirrors of the transfer line are motorized to allow for remote adjustment of the beam path. The last lens just before the vacuum chamber is used to remotely steer the beam over the cathode in order to well center the beam within a fraction of a mm.

All relevant parts of the laser system are controlled or adjustable via a computer system. It is mainly used to control the operation of the laser system. It is integrated into the TTF control system, so that TTF operators have the possibility to control basic parts of the laser such as switching it on and off, setting flashlamp currents, and the number of pulses in the train. An SPS based system surveys safety relevant parameters like water flow, temperatures, status of power supplies, etc. providing a reliable interlock system. The standard TTF timing system is used to provide all necessary triggers.

3. Performance and running experience

The performance of the laser system measured during the last run are typical performances in the sense that these values have been reached routinely during operation. Table 1 shows the measured performance compared to the specification. Most of the goals have been reached or are even surpassed: the energy per pulse is 50 μJ (peak performance 100 μJ) largely sufficient to produce an 8 nC beam with the given cathode. The train-to-train energy stability and the pulse-to-pulse stability within the train (train flatness) is better than 5% (peak–peak), an rms value of 2% is being reached averaged over 20 shots. The phase stability is better than 1 ps, the feedback system is working without failures. Fig. 2 shows an oscilloscope trace of the phase with respect to the reference phase of the 1.3 GHz RF signal. Also shown is the pulse train output of the PTO and the amplified train after conversion into the green, measured with fast photodiodes. The laser pulse length in the fundamental wavelength has been measured with a standard autocorrelation technique giving a pulse length of 10 ps (sigma). A streak camera [8] with a resolution of 2 ps has been used to measure the pulse shape in the UV, two examples are shown in Fig. 3. For nominal flashlamp currents averaged over several measurements a pulse length of $\sigma_t = 7.1 \pm 0.6$ ps is obtained. This is within the specified range. However, shorter pulses are required to produce longitudinal flat-top-beams which help to reduce the beam emittance. It was foreseen from the beginning, that the ambitious goal of 2 ps could not be reached in the first phase. At present, an upgrade project is going on with the goal to reduce the pulse length.

As a fast and simple method, the phase scan technique [9] has been used to verify the laser pulse length during the run. In fact, this method revealed lengthening of the laser pulse by a factor of 2 due to a fault in the PTO laser head.

The UV transverse beam profile during the last run was not satisfactory. Inhomogeneities induced by the frequency conversion process are larger than specified. Effort is going on to improve the quality, using an additional spatial filter in the UV beam line and to reduce the focussing into the frequency conversion crystals.

The laser has been continuously operated during the run from mid December 1998 to mid March 1999 (except for the last week of 1998) on a 24 h/day

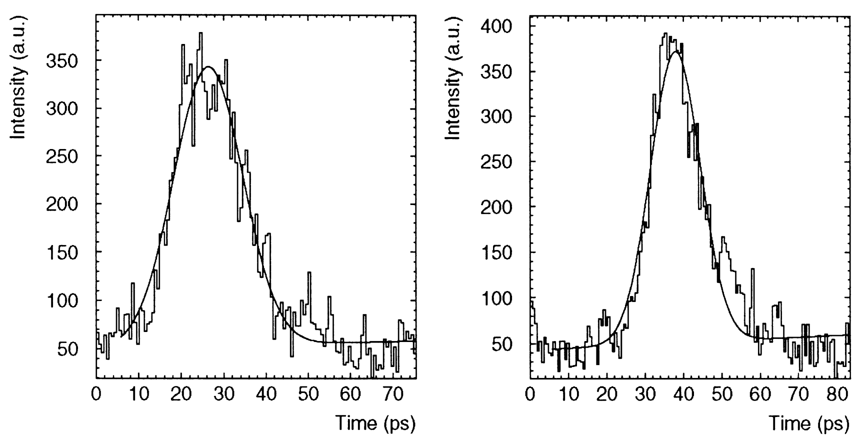

Fig. 3. Two examples of laser pulse shapes measured with a streak camera at 262 nm. The pulse length determined by a fit to a Gaussian profile is $\sigma_t = 6.3 \pm 0.6$ and 8.0 ± 0.1 ps, respectively.

bases. The total up-time exceeded 2000 h or 8×10^6 shots running at 1 Hz. The total uptime was 99% of the running time, the laser was available for beam 97% of the time. Besides routine maintenance like replacing flashlamps, no major failure of the system occurred, however, the complete PTO laser head was replaced to achieve the anticipated pulse length. Replacing major components is easily possible because a copy of the laser system is in operation at MBI, used for further developments.

4. Conclusion

In general, the first running period with the laser system under realistic conditions was a success. The availability during the 2000 h was an impressive 97% running within its specification. This shows, the importance of a robust and reliable design of lasers intended to be used in user facilities. Also the computer controlled operation of the laser and its integration in the TTF control system is essential for a successful operation. Further long-term tests have to follow, especially running with higher repetition rates.

This work was done within a cooperation between DESY, Hamburg and the Max-Born-Institut, Berlin.

Acknowledgements

We like to thank K. Rehlich, O. Hensler, and A. Agababyan for integrating the laser into the TTF control system, and M. Staack for his work on the laser interlock system.

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