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VUV FEL driven RF gun

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Abstract

In this paper we describe the regeneration of electron bunches from the RF gun by back-reflected radiation from VUV SASE FEL at the TESLA Test Facility (TTF) at DESY. The SASE FEL was running at the wavelength 96 nm with 30–100 fs pulses, SASE pulse energy was up to 20 μJ. "Nominal" electron bunches for lasing were produced by RF gun with Cs_2Te photocathode driven by UV quantum laser system. "Parasitic" bunches with a charge up to 1–1.5 nC were extracted from the RF gun due to VUV FEL radiation reflected from the mirror (placed downstream of the undulator) to the cathode. Nontrivial dependence of a charge on a SASE pulse energy was found.
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1. Introduction

Successful operation of a vacuum ultraviolet (VUV) free electron laser (FEL) with unique parameters (wavelength range 80–120 nm, 30–100 fs pulses, gigawatt level of power) [1,2] has allowed to perform pioneering experiments [3,4] at the TESLA Test Facility (TTF) at DESY.

In this paper, we present the results of an experiment which was not originally planned at TTF. Moreover, the effect, described in this paper, was discovered by chance at the end of FEL run (February 2002). SASE FEL radiation, reflected back to the photocathode of the RF gun, has regenerated electron bunches with a reasonable charge. It is worth mentioning that for the first time an RF gun was driven by

- VUV laser ($\lambda = 96$ nm),
- free electron laser,
- femtosecond laser (30–100 fs FWHM).

Experimental demonstration of a regenerative mode of electron beam production can be considered as a milestone towards realization of the Ignited Feedback Regenerative Amplifier concept [5] for high average power CW FELs. This concept assumes that a fraction of FEL radiation is used to

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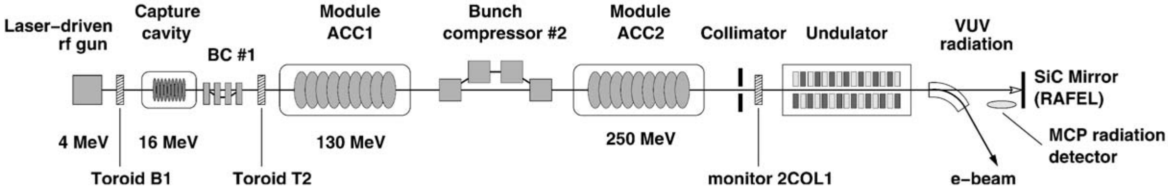

Fig. 1. The layout of the TESLA Test Facility.

drive the RF photocathode gun thus producing the next electron bunches that drive the FEL. A conventional laser system is supposed to be used only for the start-up (ignition), otherwise the required average power would be difficult to reach.

2. Experimental set-up

The layout of the TESLA Test Facility (phase 1) is shown in Fig. 1. The gun [6,7] is a $1\frac{1}{2}$-cell RF cavity operating at 1.3 GHz with a peak field of 35–40 MV/m at the photocathode. The Cs_2Te cathode [8] with diameter of 1 cm is illuminated by a UV laser system ($\lambda = 262$ nm) [9] with the spot size of 3 mm on the cathode. A quantum efficiency of the cathode in UV is 0.5%. A charge up to 3–4 nC could be extracted from the gun under these conditions, electron energy is 4 MeV. The gun is followed by a 9-cell superconducting capture cavity where the beam is accelerated up to 16 MeV. In addition, an energy chirp along the bunch is induced for compression in the first bunch compressor (BC1).[1]

The beam is then accelerated off-crest in the superconducting TESLA module (ACC1) [10] up to 130 MeV with the energy chirp for further compression in the second bunch compressor (BC2). After acceleration in the second TESLA module (ACC2) up to 250 MeV the beam passes the collimator and the undulator [11,12]. In the latter a short intense pulse of VUV radiation is generated due to SASE process [1,2]. Then electron and photon beams are separated: electron beam is deflected in the spectrometer dipole and goes to the beam dump while the photon beam goes straight downstream to the plane SiC mirror and is reflected back to the cathode of the RF gun.

The plane mirror is one of the elements of Regenerative Amplifier FEL (RAFEL) optical feedback system [13,14]. In the vicinity of the mirror, a thin golden wire is placed which reflects a tiny fraction of radiation to the micro-channel plate (MCP) detector [15]. The charge, regenerated from the cathode by VUV radiation, was detected by toroids in the injector (B1 and T2), and by the cavity monitor 2COL1 at the undulator entrance. The signal of the latter monitor was integrated into the RAFEL control system as well as the MCP signal, thus allowing to study correlation between energy of SASE pulses and charge of electron bunches, regenerated by these pulses.

3. Experimental results

During the measurements the generated wavelength was 96 nm, pulse duration was within the range of 30–100 fs (FWHM). First evidence of charge regeneration appeared as signals on photomultipliers that detect beam losses in the collimator. These signals were separated by about 650 ns (round-trip time between the cathode and the RAFEL mirror) from loss signals of nominal bunches and could be eliminated by closing the valve in the straight section behind the spectrometer dipole (or, by a distortion of the beam orbit in the undulator in order to suppress SASE process).

For the following measurements we increased the launch phase for nominal bunches in the gun by 5°. In addition, path length in BC2 was increased by about 7 mm what gave 10° delay for a VUV pulse to arrive to the cathode. At this operating point, therefore, a launch phase for

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[1] In the nominal mode of FEL operation [1] the first bunch compressor was switched off.

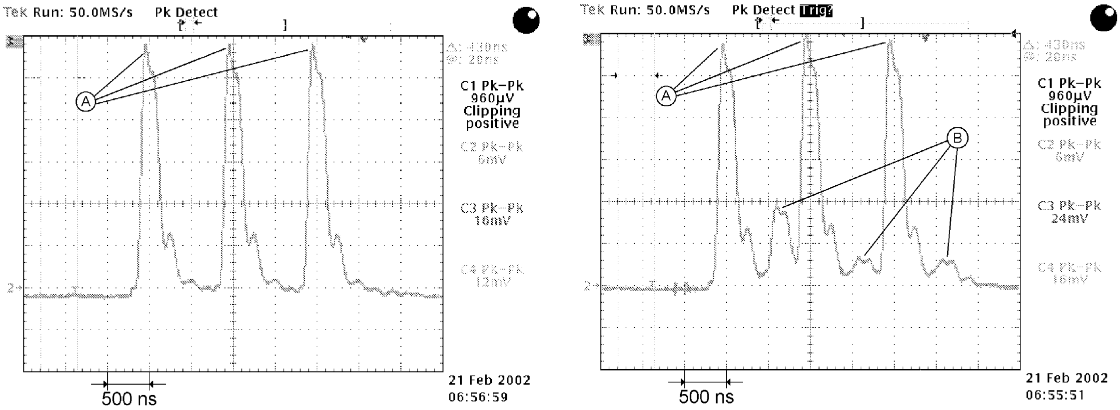

Fig. 2. Signals from the toroid T2. Left: SASE off, right: SASE on. Charge of "nominal" bunches (marked with A) is 3 nC. Regenerated bunches are marked with B.

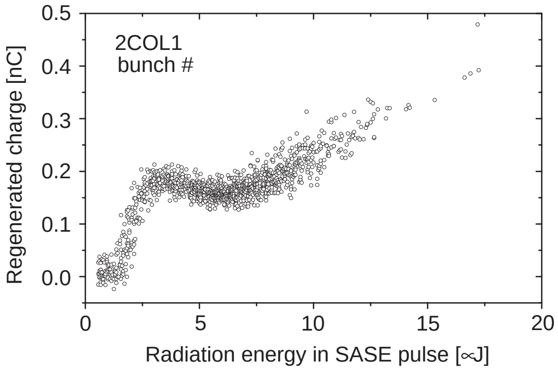

Fig. 3. Charge measured at the monitor 2COL1 versus SASE pulse energy.

regenerated bunches was at least 15°. Field at the cathode was 39 MV/m. After optimizing SASE signal we measured reasonably high charge at the injector toroids: up to 1.5 nC at B1, and up to 1 nC at T2 (see Fig. 2). Maximal SASE pulse energy was about 20 µJ.

Since SASE pulse energy was fluctuating, regenerated charge was also fluctuating. Fortunately, it was possible to do correlation measurement using MCP signal and the signal from the monitor 2COL1 because both signals were integrated into the RAFEL control system. The results of such measurement for the first bunch are presented in Fig. 3. Similar correlation plots were obtained for the other bunches. From peak values of the charge measured by the monitor 2COL1 and by injector toroids we estimate the transmission from the gun exit to 2COL1 at 30%. A reason for the dip and the following growth of charge in Fig. 3 is not yet understood. Note that the spread of the data points in Fig. 3 is mainly due to electronic noise.

One can estimate a quantum efficiency of the cathode at $\lambda = 96$ nm during the measurement. First, we determine the fraction of a measured SASE pulse energy which reaches the cathode. From geometrical optics (since the divergence of radiation and the distance from source—undulator exit—are known) we estimate that the cathode accepted about 10% of photons in a radiated pulse.[2] A reflection coefficient of the RAFEL mirror was 0.3 ± 0.1. Thus, one gets about 1.4×10^{10} photons incident on the cathode per 1 µJ of radiated energy (a photon energy is 13 eV). Taking into account the above mentioned charge transmission from the gun to the monitor 2COL1 (30%), from the slope in the initial part of the correlation plot one estimates the quantum efficiency at $15 \pm 5\%$.

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[2] For more accurate estimate one should take into account diffraction on apertures in accelerator. Of major importance is the collimator aperture with the 6 mm diameter. Calculations show that diffraction effects can change the geometrical optics results by some 20% and lead to an inhomogeneous distribution of intensity on the cathode.

Acknowledgements

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