Use of micro-channel plate for nondestructive measurement of VUV radiation from the SASE FEL at the TESLA Test Facility

B. Faatz [a], A.A. Fateev [b], J. Feldhaus [a], C. Gerth [a], U. Hahn [a], U. Jastrow [a], M. Jurek [c], J. Krzywinski, [c] N.I. Lebedev [b], M. Meschkat [a], V.A. Petrov [b], T.V. Rukoyatkina [b], E.L. Saldin [a], E.A. Schneidmiller [a], S.N. Sedykh [b], V.S. Shvetsov [b], W. Sobala [d], K.P. Sytchev [b], V.V. Tarasov [b], K. Tiedtke [a], R. Treusch, [a] M.V. Yurkov [b]

[a] *Deutches Elektronen Synchrotron (DESY), 22607 Hamburg, Germany*

[b] *Joint Institute for Nuclear Research, Dubna, 141980 Moscow Region, Russia*

[c] *IP PAS, Warszawa, Poland*

[d] *Institute of Nuclear Physics, Cracow, Poland*

Abstract

In this paper we describe the radiation detector for a nondestructive measurement of VUV radiation. Detector consists of a thin gold wire scattering tiny fraction of the SASE FEL radiation onto a micro-channel plate (MCP). Such a simple system meets all the requirements for the VUV radiation detector. Its dynamic range for intensity measurements covers up to eight orders of magnitude which ideally fits the operating range of a SASE FEL. The described detector is used in the RAFEL experiment being under preparation at the TESLA Test Facility at DESY.

1 Introduction

The Regenerative FEL Amplifier (RAFEL) project [1,2] is under development at the DESY TESLA Test Facility. Realization of this project will allow to increase the brilliance of the output radiation by two orders of magnitude with respect to single-pass scheme and obtain the light source with laser-like characteristics. This becomes possible due to installation of narrow-band optical feedback system in the high-gain FEL amplifier. The base of the optical feedback system at TTF is equal to 66.5 m (half the distance between two electron bunches when the accelerator is operated in a 2.25 MHz multibunch mode). Layout of RAFEL at TTF is shown

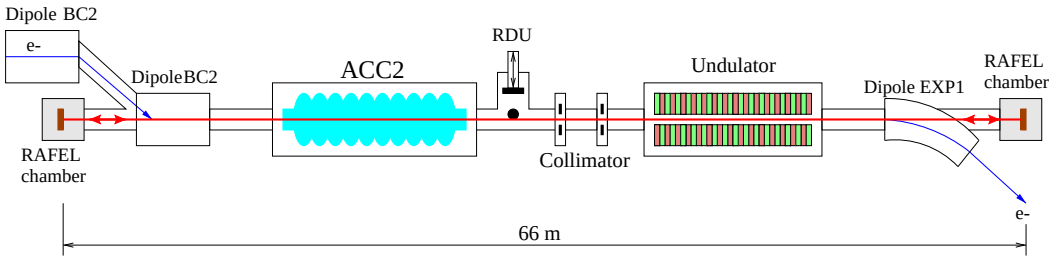


Fig. 1. Layout of the regenerative FEL amplifier at the TESLA Test Facility

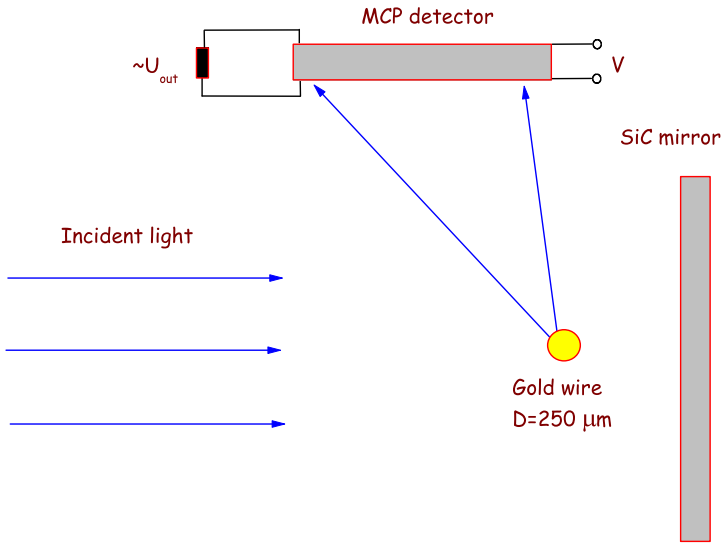


Fig. 2. Scheme of non-destructive radiation detector

in Fig. 1. The RAFEL operates as follows. The first bunch in a train of up to 1800 bunches amplifies shot noise and produces intense, but wide-band radiation. A fraction of the radiation is back-reflected by a mirror. The spherical grating in Littrow mounting which is installed in a straight section in the electron bunch compression area between the first and the second accelerator module, disperses the light and focuses a narrow band of radiation back on the entrance of the undulator to seed next electron pulse. After several round-trips output radiation spectrum approaches transform-limited width and output power reaches saturation level.

Specific features of the TTF FEL do not allow us to use its photon diagnostic system for monitoring an optical beam at operation in the RAFEL mode which forced us to develop compact, nondestructive diagnostics of VUV radiation. At the moment such diagnostics has been developed and successfully tested at TTF FEL.

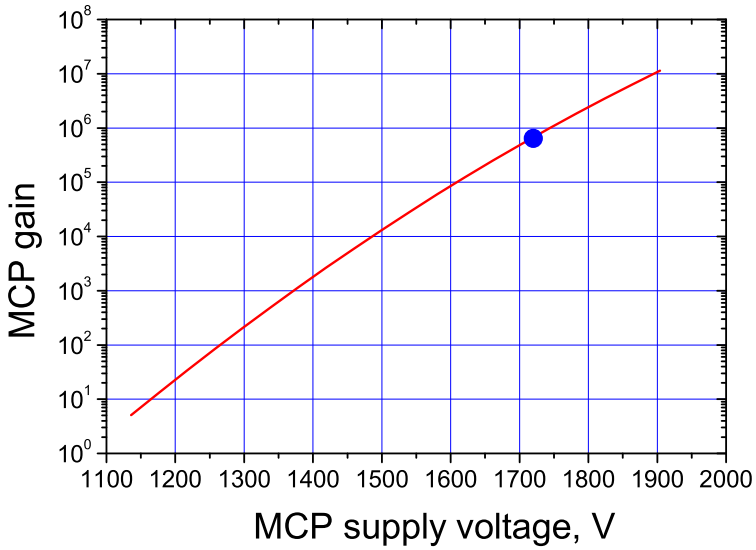


Fig. 3. MCP gain versus applied voltage. The circle is a reference point corresponding to intensity of spontaneous radiation from TTF FEL undulator at 1 nC and energy of 230 MeV

2 Principle of operation

Principle of nondestructive optical beam monitoring is illustrated in Fig. 2. A thin (0.25 mm in diameter) gold wire is installed in front of each optical element (mirror or grating). A tiny fraction of the incident radiation is reflected in transverse direction and detected by a micro-channel plate (MCP). The MCP consists of a large number of thin conductive glass capillaries which work as an independent secondary-electron multipliers and form a two-dimensional secondary-electron multiplier as a whole. We use the MCP of F4655-type manufactured by the Hamamatsu Corporation. These device is directly sensitive to UV/VUV radiation with high detection efficiency. The MCP amplification coefficient can be easily tuned in a wide range by changing power supply voltage which is applied to MCP assembly. These features make an MCP a perfect detector for monitoring VUV radiation generated by TTF FEL.

Specific feature of MCP is nonlinear dependence of the gain on the voltage applied, so special efforts have been directed for calibration procedure (manufacturer of MCP does not provide the calibration characteristics with required accuracy). Calibration of MCP gain has been performed directly at the TTF with VUV incoherent radiation from the TTF FEL undulator. The stability of this source is mainly given by fluctuations of the bunch charge and was about 5% rms during calibration run. Time duration of one radiation pulse is about one picosecond. The intensity of radiation was changed by means of changing the bunch charge and inserting of diaphragms with different aperture between the TTF FEL undulator and diagnostic chamber. Local gain characteristics were measured at different levels of radiation

intensities and then general gain curve was reconstructed in a wide range of MCP power supply voltages. An absolute setting of MCP gain was performed in the regime of single photon detection. In the region of lower power supply voltages these data were supplemented with similar measurements performed by means of Xe flash lamp. The gain curve outside calibrated region was extrapolated from experimental points. General gain characteristic of MCP-based detector is shown in Fig. 3. It is seen that detector is capable to monitor the radiation in the whole range of SASE FEL operation up to saturation level (between six and seven orders of magnitude with respect to the level of spontaneous emission). The circle at the gain curve in Fig. 3 is a reference point corresponding to the energy of the radiation pulse of spontaneous radiation from TTF FEL undulator (about 1 nJ within coherent angle) at the bunch charge of 1 nC and energy of 230 MeV. Such absolute calibration gives us the possibility for absolute measurements of the radiation energy in the radiation pulses.

3 Experimental results

The MCP-based photon detectors are installed in both RAFEL chambers and are in operation at the TTF FEL during one year. Our experience shows that at normal operating regime of the accelerator the background (electron beam and dark current losses) almost does not disturb signal which allows us to monitor very low levels of VUV radiation intensities. For example, we can detect simultaneously the

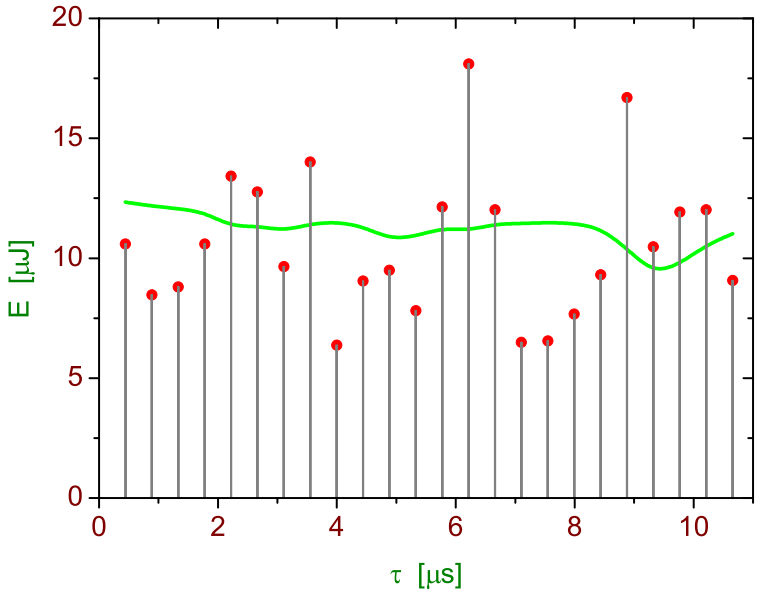


Fig. 4. On-line monitoring of the radiation at TTF FEL. The circles represent a train of radiation pulses produced by TTF FEL. Solid curve is average over many macropulses.

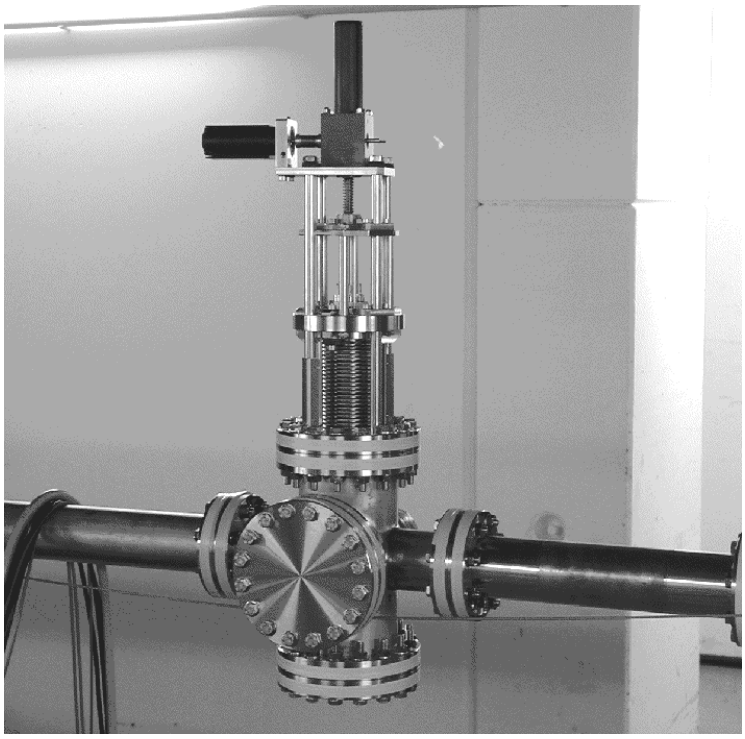


Fig. 5. Photo of radiation detector unit installed at the TTF accelerator

direct SASE radiation pulse from undulator and the same pulse passed complete round-trip in the optical feedback system of the RAFEL [2]. This is very effective tool for final alignment of optical elements of the RAFEL. Our experience also shows that use of MCP-based detector significantly simplifies tuning the SASE regime, since it detects reliably very small increase of the radiation intensity at a level of a few per cent at normalization of the signal to the bunch charge.

At the moment MCP-based detector installed downstream the undulator is routinely used for on-line monitoring of SASE FEL radiation and allows one to measure the energy of individual radiation pulses. Figure 4 illustrates typical macropulse of the TTF FEL operation at 2.25 MHz. The relative accuracy of these measurements is better than 5%. One should not wonder that large fluctuations of the bunch-to-bunch radiation energy occur. These is intrinsic property of the single-pass FEL amplifier starting from shot noise. The use of such a precise tool as MCP-based radiation detector gave us the possibility to perform precise study of statistical properties of the SASE FEL radiation [3].

During last shutdown we installed an additional radiation detector unit (RDU) in front of the undulator (see Fig. 5). The purpose of this detector is alignment and monitoring the seeding radiation pulse at the undulator entrance. This unit also uses thin reflecting wire and MCP detector. The wire is placed horizontally and is movable in vertical direction within ± 20 mm with respect to the axis of the accelerator. With this device we can measure simultaneously signals corresponding to the electron beam pulse, radiation pulse propagating from the mirror at the undulator exit to the grating, and the seeding pulse reflected from grating. This becomes possible be-

cause all these pulses are separated in time. Scanning with a wire gives us averaged spot size and positions of the electron beam and the radiation pulses. Background conditions at the location of RDU are quite moderate for performing precise measurements. One of the results is first experimental verification of the fundamental feature of the SASE FEL radiation: fluctuations of the radiation intensity after the narrow-band monochromator follows negative exponential distribution [3].

Acknowledgments

From the side of JINR and IP the work has been funded by the grant program of the special purpose use of the Polish contribution to JINR. We thank I.N. Meshkov, J.R. Schneider, D. Trines and A. Wagner for interest in this work and support. We thank all staff of the TESLA Test Facility for fruitful collaboration and help in solving technical problems.

References

[1] B. Faatz et al., Nucl. Instrum. and Methods **A429**(1999)424

[2] B. Faatz et al., ”Alignment of the optical feedback system of VUV Regenerative FEL Amplifier at the TESLA Test Facility at DESY”, Presentation at FEL2001 Conference

[3] M.V. Yurkov for TTF FEL Team, “Statistical properties of SASE FEL radiation: experimental results from VUV FEL at the TESLA Test Facility at DESY”, Presentation at FEL2001 Conference