Alignment of the optical feedback system of VUV Regenerative FEL Amplifier at the TESLA Test Facility at DESY

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Abstract

In this paper we describe optical feedback system of VUV Regenerative FEL Amplifier (RAFEL) at the TESLA Test Facility at DESY. The aim of the RAFEL experiment is to construct fully coherent, tunable VUV radiation source by means of applying narrow-band optical feedback in the VUV SASE FEL operating currently at DESY. One of the problem of the realization of the RAFEL is severe requirements for the angular stability of the optical elements (about few microradians). This problem has been solved by means of installation of active alignment system with reference laser. Another problem is alignment of optical elements separated by 65 meters within complicated experimental conditions connected with aperture limitations (down to 6 mm). This problem has been solved in two steps. Preliminary alignment with an accuracy of about 80 microradians has been performed with laser alignment system and OTR screens used at the TTF accelerator for electron beam diagnostics. Final alignment has been performed with VUV SASE FEL radiation. Measured feedback coefficient is about 1 per cent and is in agreement with designed value.

1 Introduction

A VUV/soft X-ray SASE FEL (self amplified spontaneous emission free electron laser) is being under construction at the TESLA Test Facility at DESY [1,2]. At the moment Phase I of the TTF FEL facility is in operation continuously covering wavelength range between 80 and 180 nm [3,4]. Despite SASE FEL is capable to provide much higher peak brilliance than synchrotron radiation sources, it still possesses a high potential for its further increase. Mainly brilliance of the output radiation from the SASE FEL is limited by poor longitudinal coherence of the radiation: it consists of a large number of statistically independent wavepackets. This is natural consequence of the start-up from shot noise of the FEL amplification process. An improvement of the longitudinal coherence is possible only when coherent radiation from external source is fed to the undulator entrance. The power of the seed radiation must exceed significantly effective power of shot noise in the electron beam in order to obtain fully coherent radiation at the exit of the FEL amplifier. One of the solutions of the seeding problem exploits an approach of regenerative FEL amplifier [5] with narrow band optical feedback [6]. Our previous studies have shown that RAFEL might be an ideal source of powerful, tunable, fully coherent UV/VUV radiation with laser-like characteristics. Expected parameters of RAFEL option of RAFEL at the TESLA Test Facility at DESY are presented in Table 1.

Table 1
VUV Regenerative FEL amplifier at DESY

Electron beam	
Energy	180-260 MeV
Charge per bunch	1 nC
Peak current	500 A
Bunch separation	444 ns
Undulator	
Period	2.73 cm
Peak magnetic field	0.497 T
Feedback system	
Distance between mirrors	66.4 m
Monochromator resolution	5×10^{-5}
Total transmission	5×10^{-4}
Radiation	
Wavelength	80-140 nm
Micropulse duration (RMS)	500 fs
Peak output power	300 MW
Average power	up to 25 W

2 Facility description

General layout of RAFEL option at the TESLA Test Facility is shown in Fig. 1. The installation of the feedback is greatly facilitated by the fact that there is free space available for the optical components at exactly half the distance between two electron bunches when the accelerator is operated in a 2.25 MHz multibunch mode. The optical system consists of a mirror and a grating. Because one can use optical components with good reflectivity near normal incidence, SiC appears to be particularly well suited for the energy range of the Phase I facility. This material has excellent thermal properties such that surface distortions by the average absorbed power are negligible. A simple, far too pessimistic estimate shows that the high peak power should also

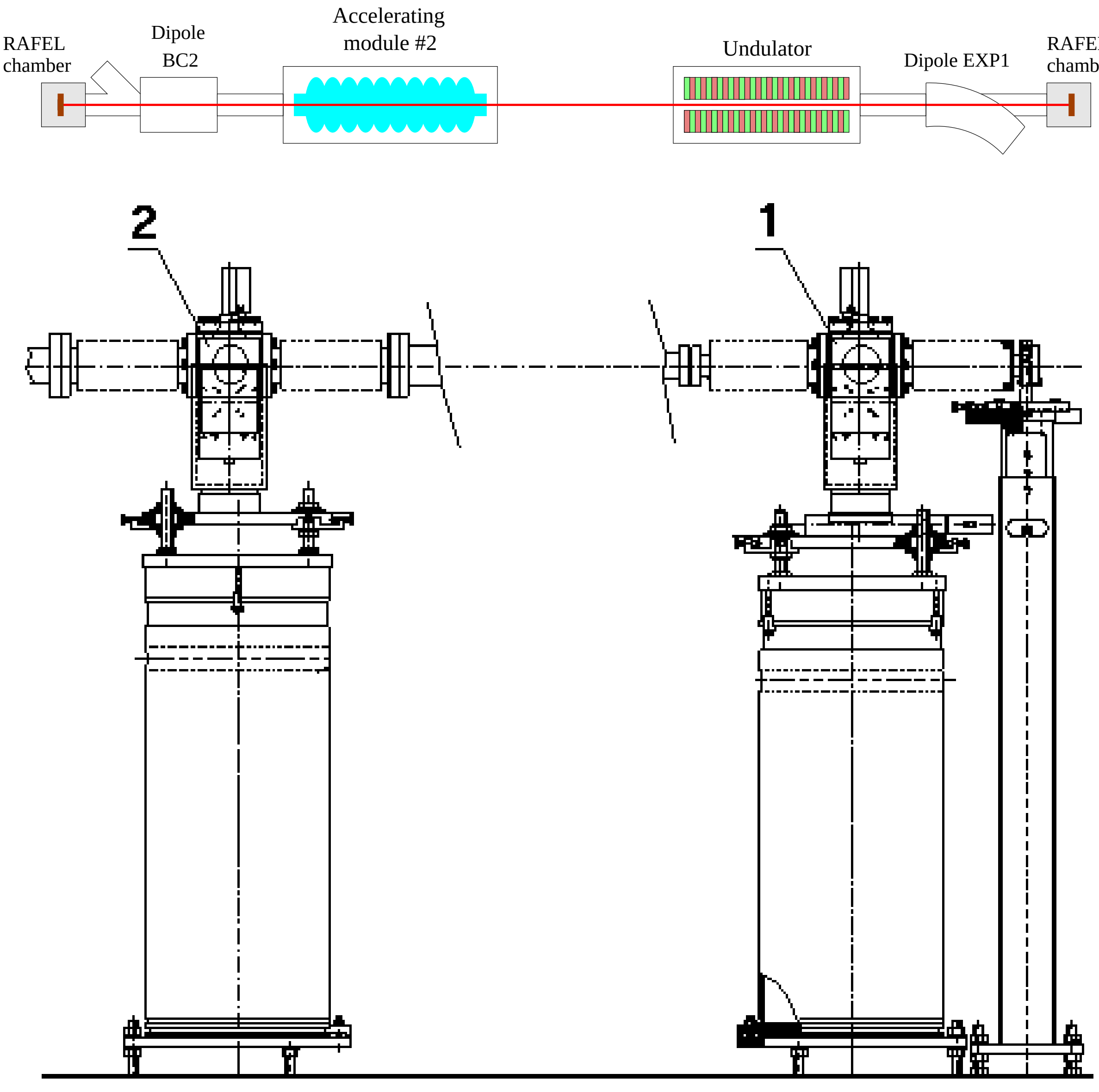

Fig. 1. General layout of regenerative FEL amplifier at the TESLA Test Facility. Here 1 is mirror assembly, and 2 is grating assembly

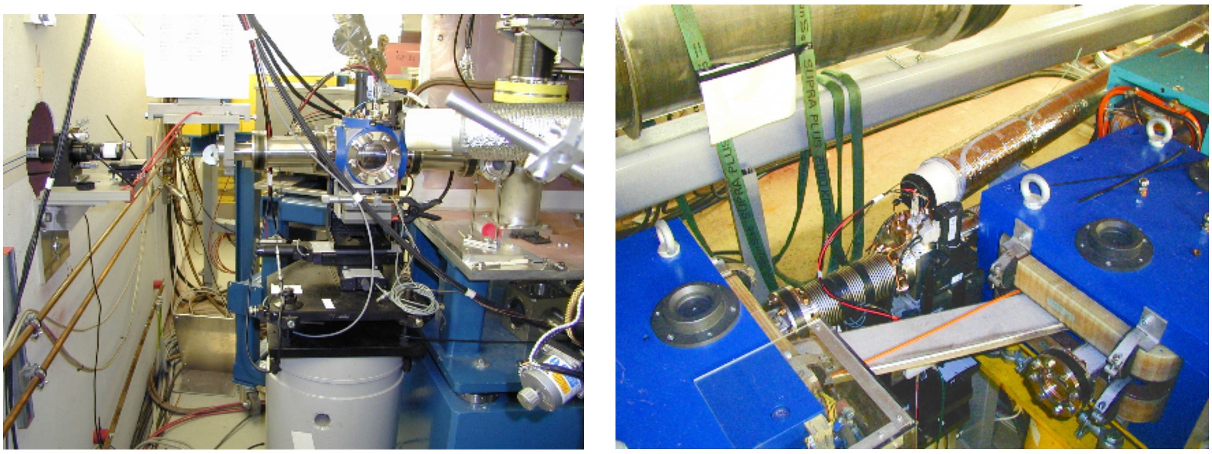

Fig. 2. Mirror (left) and grating (right) assembly mounted at the TTF accelerator

not pose a serious problem. If the energy absorbed per pulse were transformed into heat within the same absorption volume, the temperature would increase by about 1000 K — far too little to cause laser ablation.

The RAFEL at the TESLA Test Facility 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 plane SiC 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.

At present all RAFEL equipment is installed at the TTF accelerator. It consists of three elements: mirror assembly (installed 14 meters downstream the undulator), grating assembly (installed in the bunch compressor area, 35 meters upstream the undulator), and radiation detector unit (installed 6 meters upstream the undulator). Figures 1 and 2 show the mirror and the grating assembly at TTF accelerator. Each assembly consists of a vacuum chamber, a set of translators and a rigid support. The optical elements (mirrors and gratings) are fixed firmly inside the vacuum chambers. The tuning of the optical elements is provided by means of translation of the whole vacuum chamber. The chambers are installed on the translators having sufficient number of degrees of freedom.

The vacuum chambers have similar design. A plane SiC mirror and radiation detectors (MCP and photodiode) are mounted inside the vacuum chamber of the mirror assembly. Tiny fraction of radiation is scattered to the detectors by a thin gold wire or wire grid, thus providing the possibility of non-destructive monitoring. The following elements are mounted inside the vacuum chamber of the grating assembly: a curved SiC mirror, curved grating, an optical prism, and radiation detectors. The design of the grating vacuum chamber allows one to move all the elements out of the beam axis, thus providing sufficient aperture for the electron beam transport in the mode of the TTF Linac operation without bunch compressor 2 (BC2). Each vacuum chamber has a viewport for laser pre-alignment of the optical elements. During recent shutdown we installed additionally non-destructive monitor of the radiation in front of the undulator [7] which allows us to detect position of the light beam and to measure the spectrum of the radiation.

In order to minimize effort and risk, the optical system has been simplified as much as possible, particularly in order to facilitate the alignment and stability of the system at a distance of 66.4 m between mirror and grating. Each assembly is equipped with an active laser alignment system for stabilization of angular position of the vacuum chambers similar to that used at Duke University [8]. The active alignment system provides accuracy of measurements of angle deviations of a fraction of microradians. Special efforts were directed to avoid mechanical resonances in order to keep oscillation amplitudes around a microradian level (see Fig. 3).

3 Alignment of the RAFEL components

3.1 Suppression of angular oscillations

One of the problems for RAFEL design was that of tight requirements for stability of optical elements. The distance from the grating assembly to the undulator entrance is of about 35 meters. The spot size of the radiation at the undulator entrance is of about 1 mm, and the transverse size of the electron beam is of about 0.1-0.2 mm. Transverse space jitter of the electron bunches and transverse walk of the optical pulse position at the undulator entrance will lead to the reduction of their overlap and degradation of RAFEL operation. Tolerance for the off-axis walk of the optical pulse is of about 0.2 mm, or about 5 microradians for angular stability of optical elements. Angular motion of the optical elements consists of two contributions. The first one are broad-band and relatively fast oscillations excited by industrial noise in the tunnel. Figure 3 shows the time structure and probability distribution of fast oscillations. It is seen that they are within tolerable limit. Long-term observations have shown that fast oscillations occur on the top of slow variation of average angular position with typical time scale of few hours. Slow angular deviations are caused mainly by temperature variations inside the tunnel and ground motion,

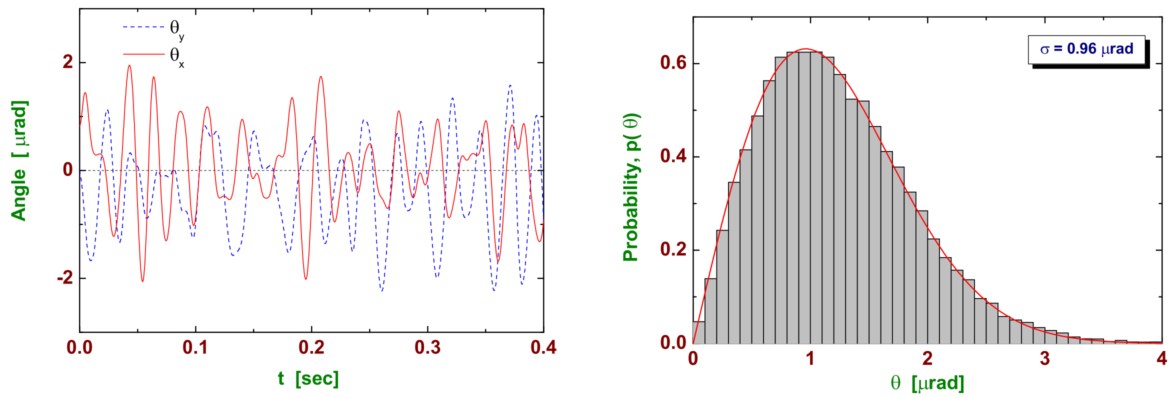

Fig. 3. Angular oscillations of the grating chamber (left) and probability distribution of the angle deviation (right). Solid line on the right plot presents Rayleigh probability distribution with $\sigma = 0.96$ μrad

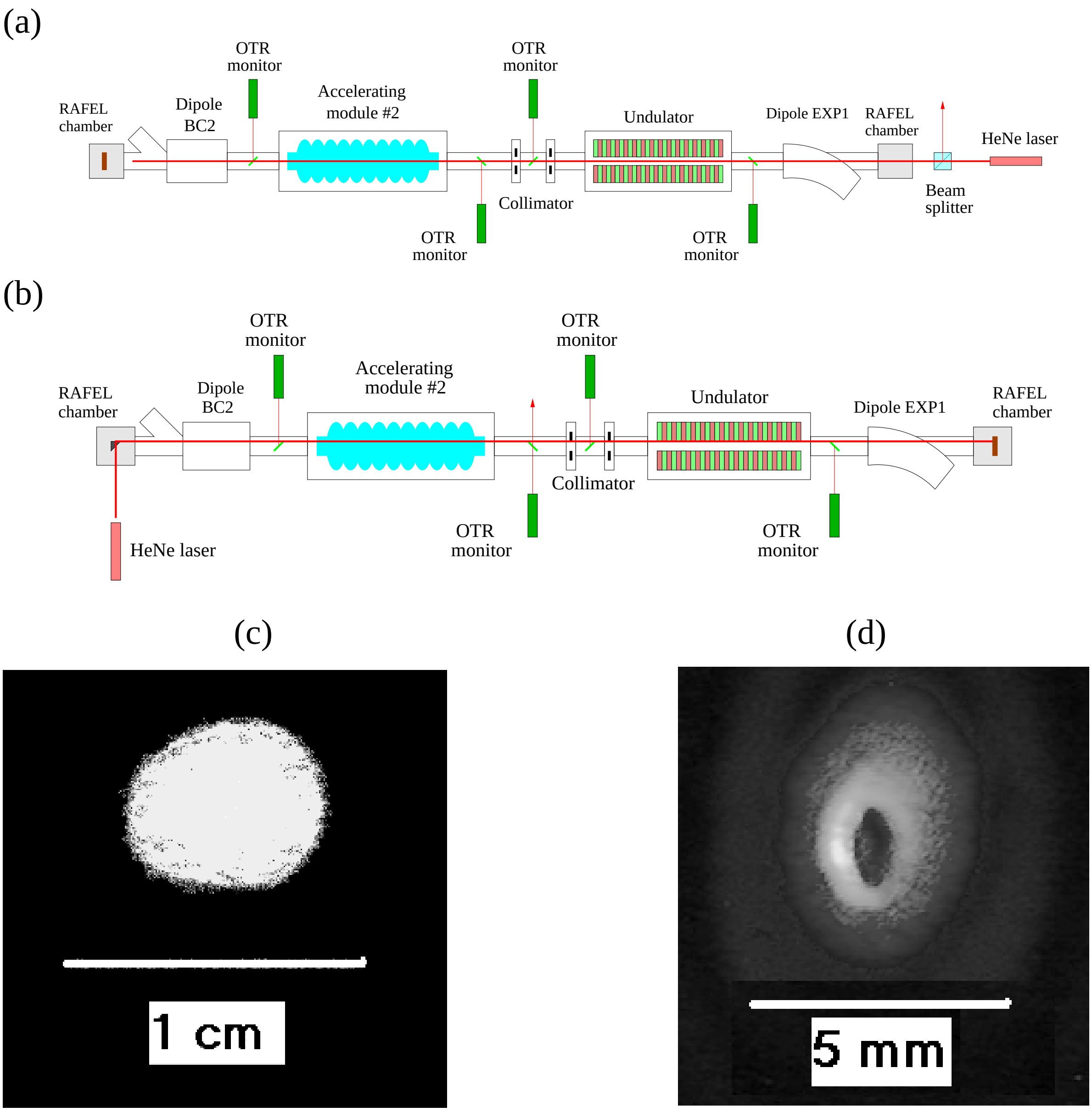

Fig. 4. Laser pre-alignment of RAFEL optical elements. Plots (a) and (c) refer to alignment of elements in the grating assembly, and plots (b) and (d) illustrate alignment procedure of elements in the mirror assembly

and may reach the value of about few tens of microradians. This slow walk is suppressed by the active laser alignment system mentioned above. As a result, RAFEL elements are kept stabilized with an accuracy better than 5 microradians.

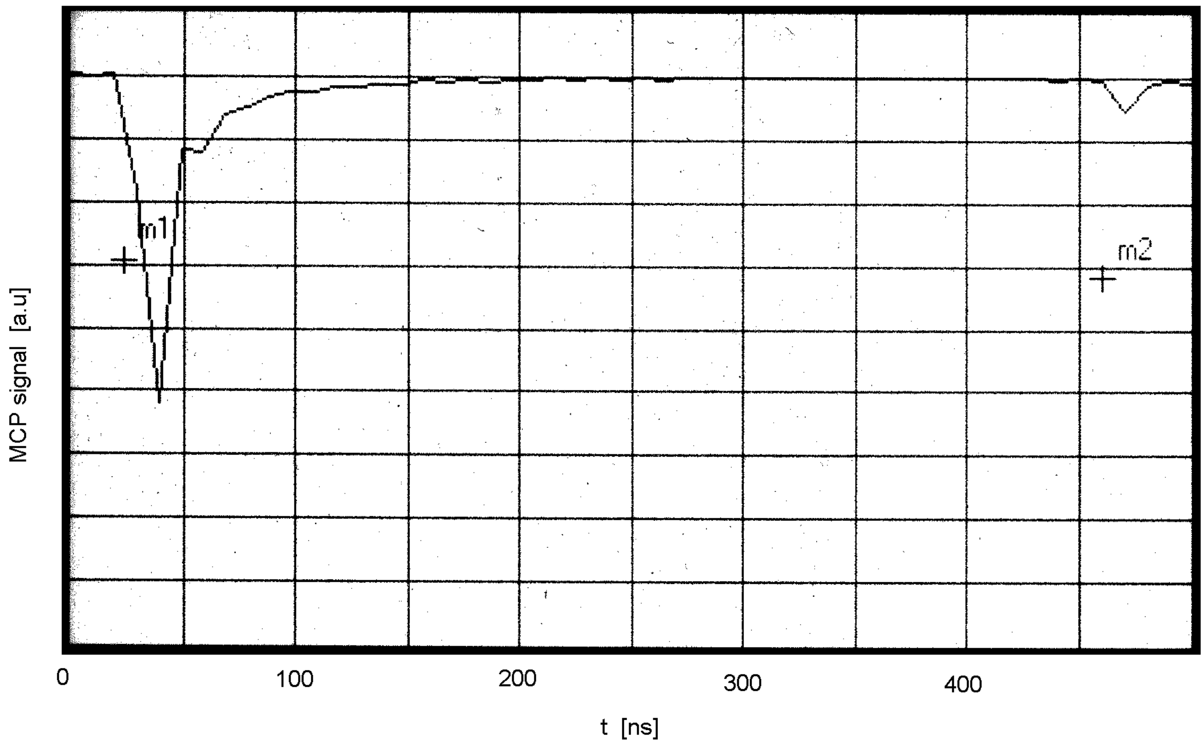

Fig. 5. MCP signal in the mirror chamber. First peak is SASE pulse. Second peak is the same SASE pulse after complete round-trip in the optical feedback system. Pulse separation is 444 ns

3.2 Alignment procedure

Specific problems of pre-alignment of optical elements of the RAFEL at TTF are connected with long base of optical feedback (66.4 m) and aperture limitations of vacuum chamber: 9 mm in the undulator and 6 mm in the collimator at the undulator entrance. Under these conditions the optical elements must be pre-aligned with an accuracy better than 80 microradians. Due to space limitation problem in the TTF tunnel, pre-alignment procedure has been performed with laser beams propagating in the vacuum chamber. Two alignment lasers have been installed at each assembly (see Fig. 4). Helpful factor for visual tracing the laser beam in the narrow vacuum chamber was the presence of optical transition monitor screens used at the TTF for observation of electron beam. These screens are manufactured of a thin captan film covered by an Al layer, and are semi-transparent for laser light. Alignment procedure have been performed in two steps. First, we aligned the mirror in BC2 area (see drawing (a) in Fig. 4). The beam passed through the whole distance between mirrors, reflected back from the mirror in the grating assembly, and is detected after the beam splitter (see photo (c) in Fig. 4). This technique guarantees obtaining of required pre-alignment accuracy due to long base passed by reference beam (130 m) with aperture limitation of 6 mm. At the second stage plane mirror in the mirror assembly have been aligned using reference laser beam from the laser installed in the grating assembly (see drawing (b) in Fig. 4). At this alignment stage we made the use of autocollimation technique with small aperture installed at the path of the laser beam 5 m in front of the mirror. Photo (d) in Fig. 4

shows the final view of back-reflected light on the rear surface of the aperture for alignment accuracy of the plane mirror of about 80 microradians.

Final alignment of the mirrors has been performed with SASE FEL radiation (see Fig. 5). VUV radiation, generated in the undulator reaches plane mirror in the mirror assembly. A non destructive radiation monitor [7] detects the radiation (left pulse in the oscillogram). Then reflected radiation propagates to the mirror installed in the grating assembly, reflected back, and is detected again in the mirror assembly (second pulse in the oscillogram). Measurement of the efficiency of the optical feedback gives the value of about 1%.

4 Present status

At the moment we finished transverse alignment of the optical elements. RAFEL experiment is in the progress. The main problem which is solved now is alignment of the longitudinal base and tuning the accelerator to reduce time and transverse space jitter of the electron bunches.

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