Status Report on a VUV Free Electron Laser at the TESLA Test Facility at DESY

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1. Introduction

The project of a superconducting linear collider is developed within the international TESLA collaboration. To verify main technical solutions of the project, the TESLA Test Facility (TTF) is constructed at DESY [1]. In addition to this main goal it was decided to construct a VUV Self Amplified Spontaneous Emission Free Electron Laser (SASE FEL) on the basis of the TTF superconducting linear accelerator [2, 3]. The first stage of the experiment is assumed to reach the wavelength about 44 nm at the electron beam energy about 390 MeV and further go down to 6 nm by increasing the linac energy up to 1 GeV. This wavelength region is very attractive with respect to possible scientific applications such as X-ray microscopy and microspectroscopy, physics and chemistry of surfaces and thin films, biological structure and dynamics, material science, etc [2].

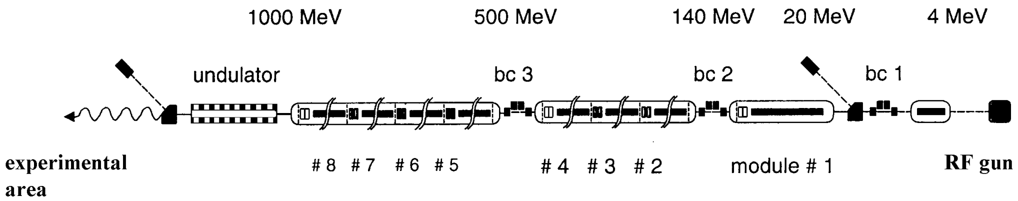

Figure 1: Schematic layout of VUV SASE FEL at the TESLA Test Facility at DESY.

2. TTF accelerator

The TTF accelerator is a high gradient superconducting linear accelerator. The design accelerating gradient is 15 MeV/m. The accelerator has a modular structure. Each accelerating module consists of eight nine-cell accelerating sections and produces the energy gain about 140 MeV [1]. To realize the VUV SASE FEL project, the energy of the TTF accelerator will be increased up to 1 GeV. A radio frequency photoinjector will be installed

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producing 1 nC charge per bunch at 1π mm mrad normalized emittance. A factor of two of the normalized emittance growth is allowed for between the exit of the injector and the entrance of the undulator. To achieve the design value of 2.5 kA peak current, three-stage bunch compression is foreseen [4] (see Fig. 1). The TTF accelerator will operate at the repetition rate of 10 Hz with 7200 bunches per macropulse separated by 111 ns [1].

3. SASE FEL process

The SASE FEL at DESY is a single pass device. The process of amplification in the SASE FEL starts from shot noise fluctuations of the beam current [5]. The bandwidth of the output radiation is about $\Delta\lambda/\lambda \simeq 2\rho$ with the resonant wavelength given by the resonance condition $\lambda = \lambda_{\mathrm{w}}(1 + K^2/2)/(2\gamma^2)$, where K is the undulator parameter, λ_{w} is the undulator period and ρ is Pierce parameter [6] ($\rho \simeq 2 \times 10^{-3}$ for the 6 nm SASE FEL at DESY). When the electron beam passes the undulator, the emitted radiation grows along the undulator exponentially with the e-fold field gain length of about $l_{\mathrm{g}} \simeq \lambda_{\mathrm{w}}/2\sqrt{3}\pi\rho$. Maximum of the radiation power is achieved at the saturation point and the FEL efficiency at saturation is about ρ. The output radiation of a SASE FEL consists of series of wavepackets (or spikes [7]). The length of each wavepacket is about $l_{\mathrm{sp}} \simeq 2\pi\lambda l_{\mathrm{g}}/\lambda_{\mathrm{w}}$, and there is no phase correlation between wavepackets.

The effect of the longitudinal velocity spread (due to the energy spread and emittance) imposes a limit on the minimal achievable wavelength in the FEL amplifier [8]. Design parameters of the SASE FEL at DESY allow to reach a minimal wavelength of about 6 nm at 1 GeV electron energy.

4. SASE FEL parameters

In Table 1 we present design parameters of the SASE FEL at DESY [9]. At phase one (300 MeV electron beam energy, 70 nm radiation wavelength) we plan to perform “a proof of principle” experiment and to test all the equipment. After this step the energy of the linac will be upgraded up to 1 GeV and 6 nm SASE FEL will produce the VUV radiation for users.

One of the most challenging parts of the equipment is the undulator. To minimize technical risk, it was decided to build a planar hybrid one [10]. While the design parameters of the period and magnetic field are close to existing ones, the length of the undulator should be rather large, about 25 m, and tolerances to the magnetic field errors are very tight. Additional complication of the undulator design arises due to the necessity to keep small size of the electron beam in the undulator which is provided by introducing strong alternating gradient focusing into the magnetic structure of the undulator. To simplify the problem of the manufacturing, assembling and tuning the undulator, it was decided to adopt a modular design. Each module will have a length of about 4.5 m. There will be gaps between the modules to place photon and electron beam position monitors and the electron beam steering stations [2].

Table 1: General parameters of SASE FEL at DESY

Electron beam	
Energy	1000 MeV
Peak current	2500 A
Normalized rms emittance (Gaussian)	2π mm mrad
rms energy spread (Gaussian)	0.1 %
rms bunch length	50 μm
Bunch separation	111 ns
Number of bunches per train	7200
Repetition rate	10 Hz
External β-function	3 m
Undulator	
Type	Planar
Period	2.73 cm
Peak magnetic field	0.4972 T
Magnetic gap	1.2 cm
Effective undulator length	25 m
Radiation	
Wavelength	6.42 nm
Bandwidth	0.5 %
Peak power	5.5 GW
Average power	130 W
# of photons per electron bunch	7×10^{13}
Peak flux of photons	2×10^{26} photons/s
Average flux of photons	6×10^{18} photons/s
Peak brilliance	4×10^{30} photons/s/mm^2/mrad^2/0.1 %
Average brilliance	10^{23} photons/s/mm^2/mrad^2/0.1%

5. Present status

During last years intensive theoretical and numerical studies of the SASE FEL process (calculations of the start-up from noise, influence of the undulator errors, emittance and energy spread effects on the FEL operation) have been undertaken (see refs. [11, 12] and references therein). The result was the optimization of the FEL parameters summarized in Table 1.

The accelerator equipment for the TTF accelerator and for the SASE FEL is being designed and constructed and some elements such as injector with thermoionic gun, components of rf equipment and the beam transport line etc, have been installed at the TTF cite (see ref. [13] for more detail). A cold model of the rf gun for the FEL mode of operation passed rf measurements at low rf power. Mechanical design of the rf gun has been completed and now it is being fabricated. The laser for the rf photoinjector (built by the Max-Born-Institute, Berlin) will be delivered to DESY in March, 1997 and a dedicated test beam line is under construction for tests of the rf gun system to be done in 1997. The design of the magnets for the second bunch compressor has been finished [14]. Calculations of the third bunch compressor are under the way, and the main problem to be solved consists in suppression the harmful influence of the coherent radiation of the short bunch in the magnets leading to the growth of the energy spread and emittance [15].

The first superconducting module of the TTF accelerator will be commissioned with the electron beam in the spring of 1997. In the end of 1997 the second bunch compressor and the photoinjector will be installed at the TTF site. After installation of the second and the third accelerating modules, in 1998 the accelerator will reach the energy up to 390 MeV which will reveal an opportunity to perform the Phase I of the SASE FEL experiment at the radiation wavelength about 44 nm [13].

At present a short undulator section of 22 cm length has been fabricated and passed mechanical tests. A 0.8 m long prototype for field measurements is expected before the end of this year. The facility for the alignment of the full-scale undulator modules is under commissioning. It is planned to assemble three undulator modules in 1998 [12].

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