PERSPECTIVE OF DELSY FOR THE FOURTH GENERATION SR FACILITY

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Abstract

The first stage of the DELSY project will be reliable SR source of the third generation [1]. An important piece of the DELSY facility is linear rf accelerator which has potential to reach the energy up to 1 GeV and average power of few tens of kilowatts. It seems be very attractive to use this accelerator for driving the complex of free electron lasers. FEL oscillators can cover the wavelength range from the far infrared down to ultraviolet. Also, it is possible to produce shorter-wavelength radiation with single-pass SASE scheme, similar to the TTF FEL. Analysis of expected parameters of the radiation from these sources allows one to conclude that the DELSY facility has good perspectives for upgrading into the fourth generation synchrotron light source.

1 INTRODUCTION

The problem of future development of radiation sources is intensively discussed during last few years. One possible way to increase the brilliance of a radiation source is to generate coherent radiation in an undulator by high-energy, low-emittance, intensive electron beams produced by linear accelerators [2, 3, 4]. This direction of development of radiation sources is named as the fourth generation of SR sources. The device itself is named as a free electron laser (FEL). The key element of a free electron laser is the undulator (or wiggler) which forces the electrons to move along curved periodical trajectories. When passing the undulator, a high quality electron beam can amplify coherently the radiation in the narrow band in the vicinity of the resonance wavelength

$$\lambda \simeq \lambda_{\mathrm{w}} \frac{1 + K^2/2}{2\gamma^2} \ ,$$

where γ is relativistic factor, and λ_{w} and K are the period and the undulator parameter of the undulator, respectively. FEL devices can be divided into two classes: amplifiers and oscillators. FEL amplifiers amplify the input electromagnetic wave from an external master oscillator (or, starts from the shot noise in the electron beam). There is no feedback between the output and the input of the FEL amplifier. The FEL oscillator can be considered as an FEL amplifier with feedback. For an FEL oscillator in the optical wavelength range the feedback is carried out by means of an optical resonator which also defines the radiation modes which can be excited in the resonator. When the gain of the radiation per pass exceeds the radiation losses in the resonator, the lasing process occurs.

The present level of accelerator technology allows one to construct free electron lasers producing coherent radiation with the wavelength spanning from far infrared band down to a value about 1 Å. Despite strong competition from conventional lasers, the FEL is recognized nowadays as a unique tool for scientific applications requiring tunable coherent radiation in the far-infrared or VUV ranges. A number of FEL-based user facility operate now all over the world. Taking into account the future perspectives of the FEL, many industrial firms undertake intensive investigations into FEL technology, aiming at constructing powerful UV FELs for industrial applications such as material processing, lithography, isotope separation, and chemical applications.

Linear rf accelerator of DELSY has potential to reach the energy up to 1 GeV and average power of few tens of kilowatts. It seems be very attractive to use this accelerator for driving the complex of free electron lasers. In this paper we perform preliminary consideration of capabilities for upgrading the DELSY linac with undulators for generation of coherent radiation.

2 COMPLEX OF FEL OSCILLATORS

At present there exist about ten specialized research centers where users use FEL radiation for scientific researches. (CLIO in France, FELIX in the Netherlands, FELI in Japan, etc). As a rule, these FELs are constructed on the base of linear rf accelerator and produce coherent radiation in infrared wavelength band. The largest FEL users facility has been built in Free Electron Laser Research Institute (FELI, Osaka, Japan). It is constructed on the base of 160 MeV S-band linear accelerator. The radiation is produced in three undulators at different energy of the electron beam. FELI facility continuously covers the radiation spectrum from far infrared down to deep ultraviolet [13]. Similar design of the FEL facility can be incorporated into the DELSY project. Existent infrastructure of the accelerator tunnel allows one to find the place for electron beamlines and undulators (see Fig. 1). Users facility can be placed in the large experimental building located nearby to the accelerator tunnel. The radiation will be transported to the users via evacuated optical lines. To provide the possibil-

Table 1: Parameters of the FEL oscillators at DELSY

	IR	UV
Accelerator		
Energy	20-80 MeV	150-200 MeV
Repetition rate	10-50 Hz	
Pulse duration	5-10 μs	
Peak current	30-50 A	
Micropulse duration	10 ps	
Norm. emittance	30 π mm-mrad	
Energy spread	1%	
Bunch separation	30-60 ns	
Undulator		
Length	2-3 m	
Period	3-4 cm	
Magnetic field	0.5-1 T	
Radiation		
Wavelength	50-1 μm	2-0.2 μm
Peak power	0.5-5 MW	
Average power	0.1-1 W	

ity of driving FEL oscillators, the peak current of the electron bunch should be increased up to the value of about 30-50 A at the value of the normalized emittance about 20-30π mm mrad. This requires upgrading of the linac with an injector on the base of gridded electron gun and subharmonic buncher. After such an upgrade of the DELSY facility we can expect to reach the parameters of the FEL

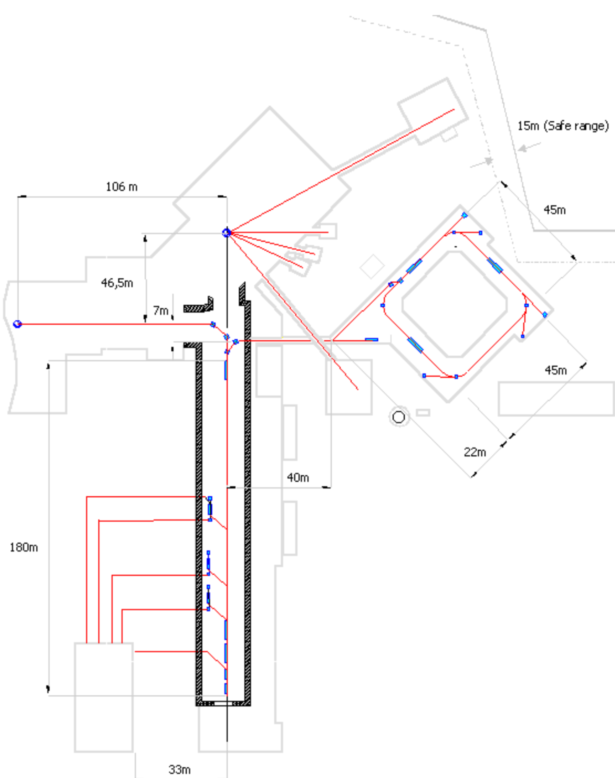

Figure 1: Layout of the DELSY facility

user facility close to that of the present leading facility at FELI (see Table 1). This facility can provide the users with tunable coherent radiation (0.2-50 μm) in parallel with the storage ring operation, excluding short interrupts connected with the filling of the storage ring.

3 VUV SASE FEL AT DELSY

Significant efforts of scientists and engineers working in the field of conventional quantum lasers are directed towards the construction of X-ray lasers. Nevertheless, this problem is still unsolved: progress in this field is rather moderate and we cannot expect a significant breakthrough in the near future. During the last decade there has been extremely rapid progress in linear accelerators, new developments in low-emittance, high-current electron guns, and successful operation of high-precision undulators. As a result, at present there exists a technological base for the construction of free electron lasers operating in the X-ray wavelength range. Since there is no possibility to use high-reflectivity optical elements at short wavelength (VUV or shorter), coherent radiation is produced by intensive electron beam during single pass of the undulator [5, 6]. The amplification process starts from the shot noise in the electron beam, and the device itself is named as self amplified spontaneous emission free electron laser (SASE FEL). The parameters of the electron beam required for successful SASE FEL operation (peak current about 1 kA, normalized emittance about 1-2π mm rad, and relative energy spread about 0.1-0.2%) are challenging, but can be achieved at the present level of accelerator technique. Recently VUV and X-ray FEL projects have been initiated at several laboratories around the world [7, 8, 9, 10, 11, 12]. The unique properties of these facilities will open up a multitude of new scientific and technical opportunities.

So, it seems to be reasonable to analyze possibilities of the for upgrading into the fourth generation SR source. In its present conditions (with existent modulators and klystrons) the DELSY accelerator is capable to produce the electron beam with the energy up to 1 GeV at average power in the electron beam of few tens of kW. This parameters are close to those of the TESLA Test Facility accelerator which is planned to drive a VUV/X-ray free electron laser. The only difference is in the time diagram of operation and parameters of a single electron bunch. Namely, TTF electron bunch has the following parameters: charge 1 nC, peak current 2.5 kA, normalized emittance 2 π mm mrad, rms energy spread 0.1%. Thorough analysis of the injection chain implemented in the TTF design shows that there is no problem to adopt it to the DELSY accelerator and achieve required parameters of the electron bunch. The electron bunch of 1 nC charge and pulse length of 2 mm is produced in laser-driven rf-gun. To achieve required bunch length (0.05 mm), one should apply technique of bunch compressors. In an ideal bunch compressor, a linear correlation between energy and longitudinal position is induced in the bunch, by passing a RF accelerator structure

Table 2: Parameters of the UV / soft X-ray SASE FEL at DELSY

Accelerator	
Energy	300 – 1000 MeV
Peak current	500 – 2500 A
Bunch charge	1 nC
rms bunch length	250 – 50 μm
Normalized rms emittance	2π mm mrad
rms energy spread	0.3 - 0.1 %
rms transverse beam size	30 – 50 μm
Number of bunches per train	100
Repetition rate	100 – 200 Hz
Undulator	
Type	Planar
Length of undulator	15 – 20 m
Period	2.8 – 3.2 cm
Peak magnetic field	0.5 – 0.8 T
Radiation	
Wavelength, λ	5 – 100 nm
Bandwidth	0.5 – 1 %
Peak power	0.3 – 3 GW
Average power	3 – 10 W
Peak brilliance*	$10^{29} - 10^{30}$
Average brilliance*	$10^{21} - 10^{22}$

*[Phot./(sec$\times$ mrad$^2\times$mm$^2\times$ 0.1 $\%$ bandw.)]

with off-crest phase. Then follows a sequence of bending magnets where particles with different energies have different path lengths. As a result the bunch tail has a shorter path and can catch up with the head, effectively compressing the bunch. Compression of electron bunch in TTF accelerator [7] is performed in three steps: at 20 MeV (from 2 mm to 0.8 mm rms), 120 MeV (from 0.8 mm to 0.25 mm rms) and 500 MeV (from 0.25 mm to 0.05 mm rms). The same elements can be installed additionally at the DELSY linac. As a result, it can produce electron bunches capable to drive SASE FEL. Table 2 gives an illustration about the parameters of the SASE FEL at DELSY which we can expect. It is seen that they fit well with parameters of another proposed SASE FELs. One should also keep in mind that in its present state maximal energy of the accelerator is limited by the peak power of the klystrons, while accelerating sections, produced at SLAC, allows higher accelerating gradient. In principle, we can expect that accelerating gradient can be increased by a factor of two by means of installing powerful SLAC-type klystrons. At the energy of 2 GeV the SASE FEL at DELSY can generate the radiation with the wavelength down to 15-20 Å. Also, a seeding option for the SASE FEL at DELSY can be realized [8] which will allow to increase the peak and average brilliance of the radiation up to the values of 10^{31} and 10^{24}, respectively (in units of photons/(sec$\times$ mrad$^2\times$mm$^2\times$ 0.1 $\%$ bandw.)). So, we can conclude that the DELSY complex has unique capability to be upgraded in perspective SR source of fourth generation.

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