A High Intensity Coherent X-ray Source Integrated into the TESLA-500 Project

M.V. Yurkov
for the TESLA FEL Study Group[1]
Joint Institute for Nuclear Research, Dubna, Russia

1. Introduction

Nowadays there exist two proposals for an X-ray FEL operating in an Å wavelength region [1, 2]. The project of a 6 nm Self Amplified Spontaneous Emission (SASE) free electron laser (FEL) is now under construction at the TESLA Test Facility at DESY [3, 4]. This project is considered as a step towards an X-ray FEL which is planned to be integrated into the TESLA-500 linear collider project [2]. It is planned to organize simultaneous operation of the TESLA linear accelerator for high energy physics and for generation of powerful coherent radiation. At present understanding of performance limitations of an X-ray FEL operation, the minimal achievable wavelength is limited by quantum fluctuations of undulator radiation and is about [5]:

$$\lambda_{\min} \simeq 45\pi \left[ƛ_{\mathrm{c}} r_{\mathrm{e}} \right]^{1/5} L_{\mathrm{w}}^{-7/15} \left[\epsilon_n^2 \frac{I_A}{I} \right]^{8/15} ,$$

or, in practical units

$$\lambda_{\min}[\AA] \simeq 4 \frac{\pi \epsilon_n [\mathrm{mm\ mrad}]}{\sqrt{I[\mathrm{kA}] L_w[\mathrm{m}]}} ,$$

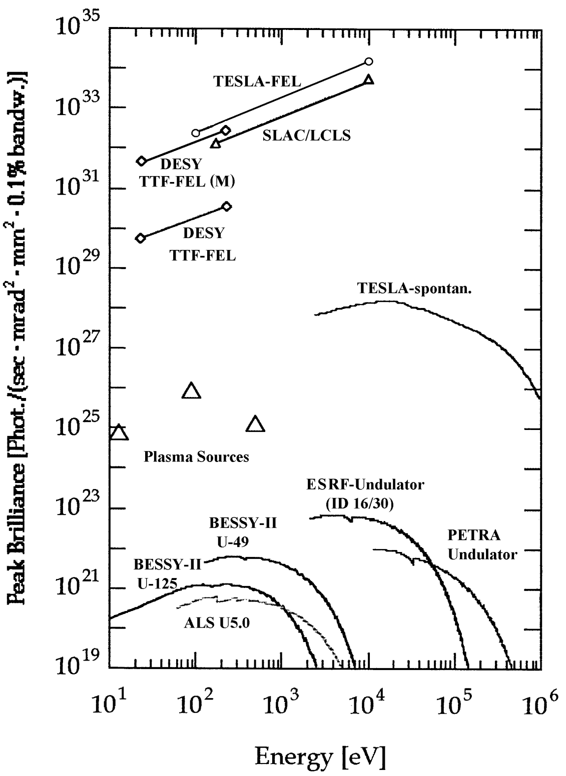

Figure 1: Peak brilliance for different radiation sources.

[1]The TESLA FEL Study Group:
ASC Samara: E.L. Saldin, E.A. Schneidmiller; **CE Saclay:** A. Mosnier; **DESY:** R. Bacher, W. Brefeld, R. Brinkmann, M. Dohlus, B. Dwersteg, H. Edwards, B. Faatz, J. Feldhaus, K. Flöttman, A. Gamp, P. Gürtler, K. Hanke, L.M. Kiernan, M. Leenen, T. Limberg, G. Materlik, T. Möller, J. Pflüger, D. Proch, J. Rossbach, J.R. Schneider, S. Schreiber, M. Seidel, J. Sekutowicz, C. Stolzenburg, K. Tesch, D. Trines, N. Walker, R. Wanzenberg, H. Weise, B.-H. Wiik, S.G. Wipf; **Fermilab Chicago:** E. Colby, T. Nicol; **INFN Milano:** R. Bonifacio, C. Pagani, P. Pierini, L. Serafini; **JINR Dubna:** I.N. Ivanov, A.Yu. Molodozhentsev, V.A. Petrov, M.V. Yurkov; **Lawrence Berkeley Laboratory:** W.M. Fawley; **Lawrence Livermore National Laboratory:** T. Scharlemann; **Los Alamos National Laboratory:** J. Goldstein, R.L. Sheffield; **Max-Born-Institut Berlin:** H. Rottke, W. Sandner, I. Will; **Polish Academy of Scienses Warschau:** J. Krzywinski; **UCLA Los Angeles:** J. Rosenzweig; **University Hamburg:** C. Kunz, B. Sonntag, H.J. Voß.

where $\lambda\!\!\!^{-}_{\rm c} = \hbar/mc$, $r_{\rm e} = e^2/mc^2$, ϵ_n is normalized emittance, I is the beam current, $I_A = mc^3/e$, $L_{\rm w}$ is the length of the undulator and m and e are the mass and the charge of the electron, respectively.

Taking into account design parameters of the TESLA linac and technical limitations on the undulator manufacturing, it was decided to consider the wavelength of 0.5 – 1 Å as an ultimate goal. The FEL complex at TESLA will cover the radiation wavelength band from 0.5 Å up to 100 Å. The region of interest for the electron energies is from several GeV up to one hundred GeV.

X-ray FELs together with different kinds of conventional undulators and wigglers will serve as radiation sources for an X-ray laboratory at TESLA. Parameters of these radiation sources exceed significantly those available at present (see Figs. 1 and 2).

A similar scenario for an X-ray laboratory is under discussion for the normal conducting S-band linear collider concept (SBLC) which is also studied at DESY. With respect to FEL parameters there is no fundamental difference, but TESLA is the preferable solution regarding the electron beam quality relevant for FEL performance (see ref. [2] for more detail).

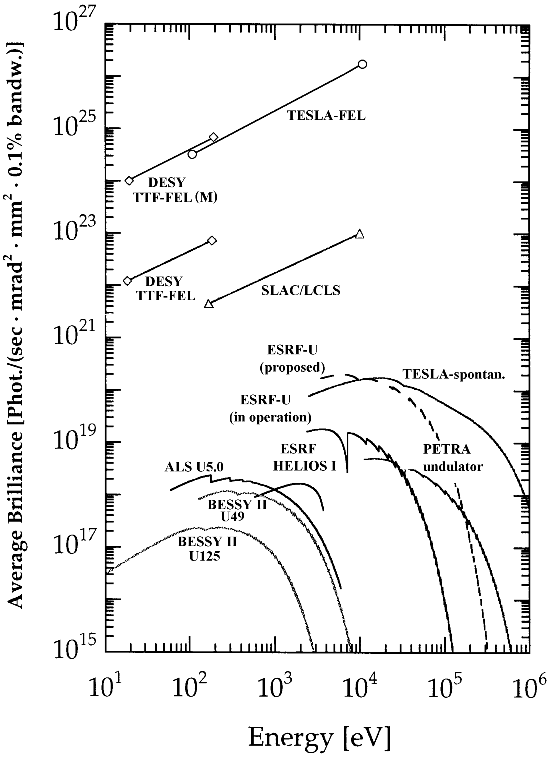

Figure 2: Average brilliance for different radiation sources.

2. X-ray laboratory

The sketch of the X-ray laboratory at the TESLA linear collider is presented in Fig. 3. Simultaneous operation of the TESLA-500 accelerator for high energy physics and for generation of radiation is provided by special time diagram of the main accelerator operation (see Fig. 4) [6]. During each operating cycle the TESLA linac will accelerate one bunch train for high energy physics experiments and another one, at lower accel-

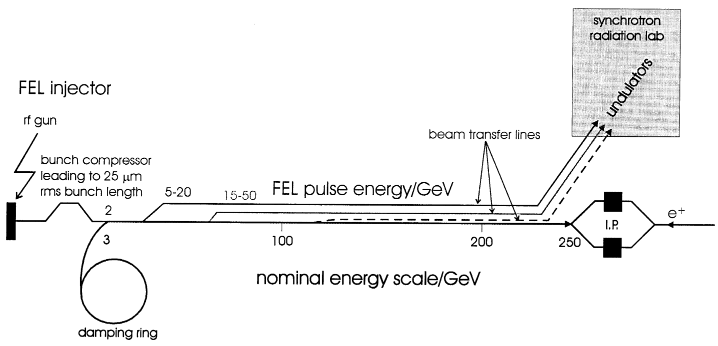

Figure 3: Schematic layout of X-ray laboratory at TESLA.

erating gradient, for an X-ray laboratory. The bunches for X-ray laboratory (1 nC charge, 5 kA peak current, 1 mm mrad normalized emittance and 23 μm rms pulse length) will be produced by a special injector consisting of photoinjector rf gun and a linear accelerator with bunch compressors. After acceleration in the main TESLA linac up to the energy of 5 – 100 GeV, the electron bunches will be directed into experimental halls of X-ray laboratory and pass different kinds of radiators (conventional wigglers for generation of synchrotron radiation and powerful VUV and X-ray SASE FELs).

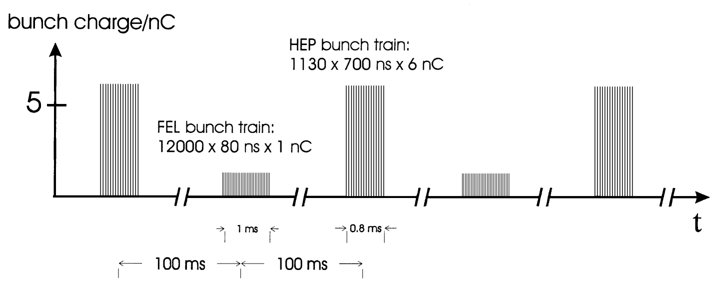

Figure 4: Time diagram of the TESLA linac operation.

3. An 1 Å X-ray FEL

It was mentioned in the introduction that quantum fluctuations of undulator radiation impose a limit on a minimal achievable wavelength in an X-ray FEL. At project parameters of the driving electron beam for the TESLA FEL (1πmm mrad rms normalized emiitance, 1 MeV rms energy spread, 5 kA peak current) and at the undulator length $L_{\rm w} \sim 50-100$ m the operation of the X-ray FEL at the wavelength near 1 Å becomes possible at the energy about 10 – 15 GeV [5]. This requires the undulator with the period about 3 – 4 cm and the value of magnetic field about $0.5-1$ T. At these parameter region the minimal radiation wavelength is achieved when the induced energy spread in the electron beam due to quantum fluctuations of undulator radiation becomes to be comparable with the initial energy spread of 1 MeV. In this case the minimal wavelength is sensitive to the initial energy spread. Parameters of the LCLS project lie in these region [1].

Table 1: Parameters of 1 Å FEL at TESLA

Electron beam	
Energy	50 GeV
Peak current	5 kA
Normalized rms emittance	1π mm mrad
rms energy spread (entrance)	1 MeV
rms energy spread (exit)	18 MeV
rms bunch length	23 μm
Bunch separation	93 ns
Number of bunches per train	11315
Repetition rate	5 Hz
External β-function	15 m
Undulator	
Type	Helical
Period	7 cm
Magnetic field	0.785 T
Undulator length	95 m
Radiation	
Wavelength	1 Å
Bandwidth	0.2 %
Peak power	200 GW
Average power	2.2 kW

In the framework of the TESLA project there is no such a strict limitation on a maximal available energy of the electron beam as in the case of the LCLS project. When increasing the energy of the driving electron beam, operation of the X-ray FEL in the 1 Å wavelength region is also possible even in the case when the energy spread in the electron beam at the undulator exit exceeds significantly the initial energy spread. Moreover, the requirements to the parameters of the undulator become to be relaxed: the undulator period should be increased at the energy increase, while the undulator field should be below 1 T. Table 1 illustrates parameters of an 1 Å X-ray FEL at the TESLA operating at the electron beam energy of 50 GeV. It is seen that the energy spread in the electron beam at the undulator exit is equal to 18 MeV which means that requirements to the value of the initial energy spread in the beam could be relaxed by one order of magnitude with respect to the operation at the energy of about 10 – 15 GeV. Preliminary calculations shows that there are also another arguments in the favor of choosing a higher energy of the driving electron beam which refer to the improvement of transverse coherence of the radiation and a higher output radiation power and brilliance.

To reach the wavelength below one Angstrom it is planned to use harmonic generation schemes (for 2-nd and 3-rd harmonics) similar to those proposed in ref. [7].

4. Conclusion

The presented parameters for an X-ray FEL at TESLA give an impression about the perspectives of coherent X-ray source at a linear collider, but they should be considered as preliminary ones. A more detailed specification will be achieved during the work on the TESLA Conceptual Design Report. In addition to powerful X-ray FELs the X-ray laboratory will be equipped with a number of undulators and wigglers for generation of spontaneous synchrotron radiation. The peak and average brilliance of the radiation from these radiators will exceed by several orders of magnitude the corresponding values for the third generation synchrotron radiation sources (see Figs. 1 and 2).

References

[1] R. Tatchyn et al. Nucl. Instrum. and Methods **A375**(1996)274.

[2] R. Brinkmann, G. Materlik, J. Rossbach, J.R. Schneider and B.-H. Wiik. "An X-ray FEL laboratory as part of linear collider design", presented at XVIII International Free Electron Laser Conference (Rome, 1996).

[3] "A VUV Free Electron Laser at the TESLA Test Facility: Conceptual Design Report". DESY Print TESLA-FEL 95-03, Hamburg, DESY, 1995.

[4] D.A. Edwards, editor, "TESLA Test Facility Linac: Design Report", DESY Print TESLA 95-01, Hamburg, DESY, 1995.

[5] J. Rossbach et al. Nucl. Instrum. and Methods **A374**(1996)401.

[6] R. Brinkmann. DESY Print, TESLA-FEL 96-01, Hamburg, DESY, 1996.

[7] R. Bonifacio et al. Nucl. Instrum. and Methods **A296**(1990)787.