MOPA FEL SCHEME AS A SOURCE OF PRIMARY PHOTONS FOR GAMMA-GAMMA COLLIDER TESLA AND SBLC

E.L. Saldin, E.A. Schneidmiller
Automatic Systems Corporation, 443050 Samara, Russia
M.V. Yurkov
Joint Institute for Nuclear Research, 141980 Dubna, Moscow Region, Russia

Abstract

This report presents description of the free electron laser system to be the source of primary photons at Lnear Collider TESLA/SBLC [1].

1 INTRODUCTION

The project of a Linear Collider is under development by the international TESLA collaboration [1]. In addition to studying e^+e^- physics, it is planned to organize the second interaction region for studying $\gamma\gamma$ and γe collisions. Gamma-quanta will be produced by means of Compton bacscattering of laser photons on the electron beam from the main accelerator [2]. To provide high conversion efficiency, the peak laser power should be not less than 300 GW. Time structure of the laser operation should be identical to that of the main accelerator. The laser pulses should be synchronized precisely with respect to the electron pulses with accuracy of about one picosecond. It is likely that the laser should be tunable, so as an optimal wavelength range depends on the collider energy. Finally, to provide a more reach program of physical experiments, the laser should provide a possibility to steer the polarization of the laser light. All these requirements make the problem of the laser for gamma-gamma collider to be not trivial, especially for the TESLA project [1, 3, 4].

Potential features of a free electron laser (FEL) allow one to consider it as an ideal source of primary photons for a gamma-gamma collider. Indeed, FEL radiation is tunable and has always minimal (i.e. diffraction) dispersion. The FEL radiation is totally polarized: circularly or linearly for the case of helical or planar undulator, respectively. A driving accelerator for the FEL may be a modification of the main linear accelerator, thus providing the required time structure of laser pulses. The problem of synchronization of the laser and electron bunches at the conversion region is solved by means of traditional methods used in accelerator techniques. FEL amplifier has potential to provide high conversion efficiency of kinetic energy of the electron beam into coherent radiation. At sufficient peak power of the driving electron beam the peak power of the FEL radiation could reach the required TW level.

The idea to use the FEL as a laser for gamma-gamma collider has been proposed in ref. [5]. More detailed study of this idea has shown that the problem of construction of free electron laser can be solved using Master Oscillator – Power Amplifier (MOPA) scheme with the driving accelerator for the FEL amplifier constructed on the same basis as the main accelerator for a linear collider [6, 7, 8, 9]. At present an option of an FEL as a laser for gamma-gamma collider is studied for different projects. While there exist different FEL configurations, an amplifier configuration has definite advantages for application in the gamma-gamma collider schemes [9]. The choice of specific technical solution depends on the parameters of the linear collider project. For instance, for the VLEPP, CLIC, JLC and TESLA projects it has been considered to use MOPA FEL scheme [3, 4, 10, 12, 13].

Designers of NLC project consider an FEL scheme using induction linac and chirped pulse amplification technique [14, 15].

2 FEL PARAMETERS

In the present study of the Linear Collider Project it has been accepted to use MOPA FEL scheme as a source of primary photons for gamma-gamma collider (see Fig. 1). Such a choice fits well to both TESLA and SBLC options. In this scheme the optical pulse from Nd glass laser ($\lambda = 1$ μm, 1 MW peak power) is amplified by FEL amplifier up to the power of about 500 GW (see Table 1). The driving beam for the FEL amplifier is produced by the linear rf accelerator identical to the main accelerator, but with lower accelerating gradient due to higher beam load. It is important that the requirements to the parameters of the FEL driving electron beam are rather moderate and can be provided by injector consisting of gridded thermoionic gun and subharmonic buncher.

Table 1 presents the main parameters of the FEL amplifier and the driving accelerator. It is seen from Fig. 2 that

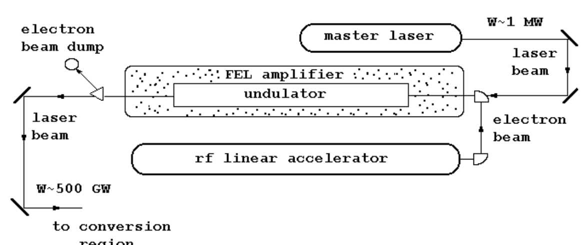

Figure 1: MOPA FEL configuration for a gamma-gamma collider

Table 1: Parameters of the FEL amplifier

Electron beam*	
Electron energy	2 GeV
Peak beam current	2.5 kA
rms energy spread	0.2 %
rms normalized emittance	$2\pi \times 10^{-2}$ cm rad
rms bunch length	1 mm
Undulator	
Undulator type	Helical
Undulator period (entr./exit)	15 cm/ 12.9cm
Undulator field (entr./exit)	10.2 kG/ 11.9 kG
Length of untapered section	17 m
Total undulator length	60 m
Radiation	
Radiation wavelength	1 μm
Input power	1 MW
Output power	500 GW
Flash energy	2.3 J
Efficiency	10 %

*Time diagram of the accelerator operation is identical to the time diagram of the main accelerator.

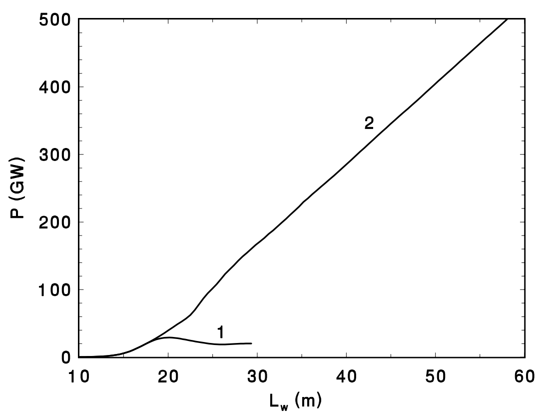

Figure 2: Output power of the FEL amplifier versus undulator length (curve 2). Curve 1 corresponds to untapered undulator.

500 GW level of output power is achieved at the undulator length of about 60 m. Total flash energy in the laser pulse is about of 2 J.

Using FEL amplifier allows one completely exclude transmitting optical elements and deliver the laser beam to the conversion region using several reflections from metallic mirrors which are rather stable to the laser radiation damage. This can be done when vacuum systems of the FEL amplifier and linear collider are combined. The first reflection mirror can be installed at a distance about several tens of meters after the exit of the undulator when the laser beam expands to the size about several centimeters from

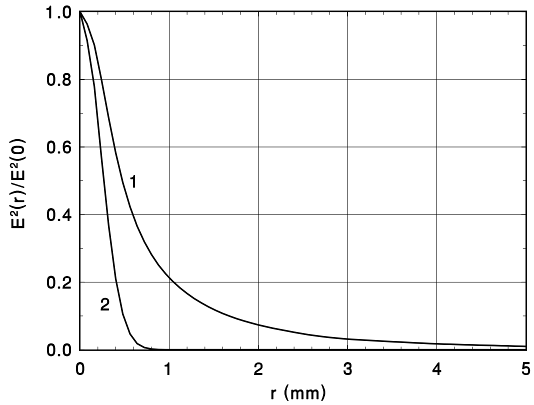

Figure 3: Radial distribution of the radiation power density (1) at the undulator exit and the electron beam current density (2).

initial size of few millimiters (see Fig. 3).

To reduce the cost of the laser system, only one free electron laser can be used. This scheme operates as follows. The FEL is installed only in one branch of the linear collider. When the laser bunch passes the focus of the conversion region, it is not dumped but is directed to the optical delay line which provides a delay time equal to the time interval between the bunches. Then it is focused on the electron beam of the opposite branch of the linear collider. Of course, this configuration provides colliding gamma-beams with the second micropulse of the collider. Nevertheless, the number of microbunches is equal to several hundreds, so it will not result in significant reduction of the integral luminosity.

3 FUTURE PERSPECTIVES

The present design has been limited with an approach which can be realized at the present level of accelerator and FEL technique. The main reserve to improve the FEL performance is to increase its efficiency which will allow to decrease the requirements to the value of the peak electron beam power. The perspectives of the FEL efficiency increase are on the way of using multi-stage FEL amplifier with diaphragm focusing line (see Fig. 4) [16, 17]. The principle of operation of this FEL scheme consists in the storing of the energy in a single laser pulse amplified by a sequence of electron bunches. This scheme has evident perspectives for the TESLA project due to a large bunch spacing. Preliminary study shows that the energy of the driving electron beam could be reduced to the value of several hundreds of MeV and the value of the peak current could be reduced by several times. The beam load in accelerator will be also reduced approximately by a factor of 3 due to higher FEL efficiency about of 30 %.

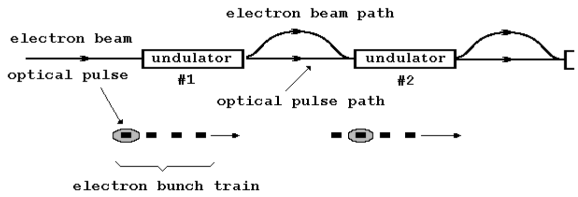

Figure 4: The scheme of multi-stage FEL amplifier. One optical pulse is amplified by a sequence of electron bunches. The peak power of the output radiation exceeds by a factor of N (number of amplification stages) the peak output radiation power of traditional single pass FEL amplifier.

4 ACKNOWLEDGMENTS

We are grateful to R. Brinkmann, N. Holtkamp, V. Telnov, D. Trines and A. Undrus for many useful discussions.

5 REFERENCES

[1] "Conceptual Design of a 500 GeV e+e− Linear Collider with Integrated X-ray Laser Facility" (Editors R.Brinkmann, G. Materlik, J. Rossbach, A. Wagner), DESY 97-048, Hamburg, 1997.

[2] I.F. Ginzburg et al., Pis'ma v ZhETF **34**(1981)514, Preprint INF 81-50, Novosibirsk (1981), in Russian.

[3] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller, Yu.N. Ulyanov and M.V. Yurkov, Preprint DESY 94-243, DESY, Hamburg, 1994.

[4] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller, Yu.N. Ulyanov and M.V. Yurkov, Nucl. Instrum. and Methods **A361**(1995)101.

[5] A.M. Kondratenko, E.V. Pakhtusova and E.L. Saldin, Dokl. Akad. Nauk **264**(1982)849, Preprint INF 81-130, Novosibirsk (1981), in Russian.

[6] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller and M.V. Yurkov, Proceedings of the Second Workshop "Physics at VLEPP" (June 2-4, 1992, Protvino, Russia), Vol. 2. p. 96, in Russian.

[7] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller and M.V. Yurkov, Proceedings of the XIII Conference on Charged Particle Accelerators (October 13-15, 1992, Dubna, Russia), Vol. 1. p. 36, in Russian.

[8] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller and M.V. Yurkov, Preprint JINR E9-94-70, Dubna, 1994.

[9] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller and M.V. Yurkov, Nucl. Instrum. and Methods **A339** (1994)583.

[10] V.A. Alexandrov, V.E. Balakin, E.A. Kushnirenko, A.A. Sery, N.A. Solyak and M.V. Yurkov, Photon linear collider 100×100 GeV based on the VLEPP physics and technology, Proc. LC 93 Workshop, SLAC, Stanford, October, 1993.

[11] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller, Yu.N. Ulyanov and M.V. Yurkov, Proceedings of the Sixth International Workshop on Linear Colliders LC95 (March 27-31, 1995, Tsukuba, Japan), KEK Proceedings 95-5, August 1995, Vol. III, p.1919.

[12] S. Hiramatsu, S. Hashimoto and Y. Ishida, Nucl. Instrum. and Methods **A355**(1995)133.

[13] R. Corsini and A. Mikhailichenko, Proceedings of the Sixth International Workshop on Linear Colliders LC95 (March 27-31, 1995, Tsukuba, Japan), KEK Proceedings 95-5, August 1995, Vol. III.

[14] K.-J. Kim, M. Xie and A.M. Sessler, Nucl. Instrum. and Methods **A375**(1996)523.

[15] Zeroth-Order Design Report for the Next Linear Collider, Appendix B, LBNL-PUB-5424,SLAC Report 474, UCRL-ID-124161 (May 1996).

[16] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller, Yu.N. Ulyanov and M.V. Yurkov, Preprint JINR E9-94-237, Dubna, 1994.

[17] E.L. Saldin, V.P. Sarantsev, E.A. Schneidmiller, Yu.N. Ulyanov and M.V. Yurkov, Nucl. Instrum. and Methods **A361**(1995)317.

[18] W.M. Fawley, Nucl. Instrum. and Methods **A375**(1996)550.