The Revised ELFA Project

E.Acerbi[1], F.Alessandria[1], P.Arcioni[2], G.Baccaglioni[1], W.A.Barletta[3], G.Bellomo[1], C.Birattari[1], R.Bonifacio[1], I.Boscolo[1], A.Bosotti[1], F.Broggi[1], M.Bressan[2], G.Conciauro[2], R.Corsini[1], L.De Salvo[1], G.Gemme[4], D.Giove[1], C.Maroli[1], R.Parodi[4], P.Pierini[1], N.Piovella[1], M.Pullia[1], G.Rivoltella[1], L.Rossi[1], V.Stagno[5], V.Variale[5], G.Varisco[1]

[1]*INFN and Università degli Studi, Milano, Italy* ; [2]*INFN and Università degli Studi, Pavia, Italy*
[3]*Lawrence Berkeley Laboratory, USA;* [4]*INFN Genova, Italy;* [5]*INFN and Università degli Studi, Bari, Italy*

Abstract

The goal of the revised ELFA project (Electron Laser Facility for Acceleration) is to operate with short bunches a high-gain free electron laser (FEL). The paper describes the main components of the experiment and discusses the choice of the parameters for the linac, the electromagnetic wiggler, the microwave generator, the waveguide and the beam and radiation diagnostics.

I. Introduction

ELFA is a high gain free electron laser designed to operate in the microwave region with the waveguide control of the group velocity of the radiation[1].

At the level of fundamental physics the goals of ELFA are to verify and characterize quantitatively:

- the self-bunching of the electron beam;
- the production of high power radiation by coherent spontaneous emission on higher harmonics in a two wiggler scheme;
- the FEL lethargy starting from noise.

The first goal includes the experimental demonstration of the existence of three different regimes of FEL operation: the steady state regime (zero slippage), the strong superradiance regime (strong slippage) and the weak superradiant regime (very strong slippage)[2]. With respect to the production of radiation the performances of a high gain FEL amplifier in the steady state regime were first measured several years ago at Livermore[3,4] using long electron pulses from a linear induction accelerator. The physics in the two superradiant regimes, however, has never been investigated experimentally. ELFA intends to study these regimes with short electron pulses by controlling the slippage with a properly designed waveguide[5].

The first two researches have also significant applications in the accelerator technology. In fact the bunching of the electrons in the picosecond or sub-picosecond domain should be able to produce electron pulses with tens of kiloamperes of peak current useful as a drive beam in a two beam accelerator[6]. Similarly, the second research can allow the production of high power coherent ultraviolet radiation in absence of a stimulating source and without starting from noise (very long wiggler).

II. Status of the Project

The general layout of the ELFA project has undergone an extensive review since its first presentation[7]. The fundamental physics goals, which are at the heart of the proposal, have gained a primary role over the technological development. The main components of the original proposal (semiconductor photocathode injector, superconducting cavities and hybrid wiggler) would require a research and development effort that would not be compatible with the time scale and economical planning of the overall experiment. In this sense our new approach has been to seek a design that could produce beams with minimum characteristics necessary to demonstrate all the physics of ELFA eliminating all non-essential technical risks and minimizing both the delivery time and the cost of the main subsystems. A general layout of the revised apparatus is shown in Fig. 1 and the main parameters are summarized in Table 1.

Table 1. Main ELFA parameters

Electron Beam	
Beam Energy	$E_k = 6$ MeV
Normalized emittance (hard edge)	$\varepsilon_n = 200\ \pi$ mm mrad
Energy spread	$\Delta\gamma/\gamma = \pm\ 1\%$
Peak current	$I > 50$ A
Microbunch length	$\tau > 35$ ps
Microbunch number	3
Repetition rate	10 Hz
Wiggler	
Wiggler period	$\lambda_w = 10$ cm
Peak wiggler field	$B_w = 1.0\text{-}3.6$ kG
Wiggler parameter	$a_w = 0.66 - 2.4$
Overall length	$L_w = 8$ m
Betatron wavelengths (m)	$\lambda_{\beta x} = 2.2 \quad \lambda_{\beta y} = 0.8$
rms field errors	0.1 %
Groove waveguide	
Width	5 cm
Height (center)	10.04 mm
Microwave radiation	
Wavelength	$\lambda_r = 3$ mm
Input power	$P_{in} = 1$ kW
Expected peak output power	$P_{out} \approx 10$ MW
FEL parameters	
Fundamental FEL parameter	$\rho \approx 2 \times 10^{-2}$
Saturation length	$L_{sat} \approx 5$ m
Gain length	$L_g \approx 0.5$ m

0-7803-1203-1/93$03.00 © 1993 IEEE

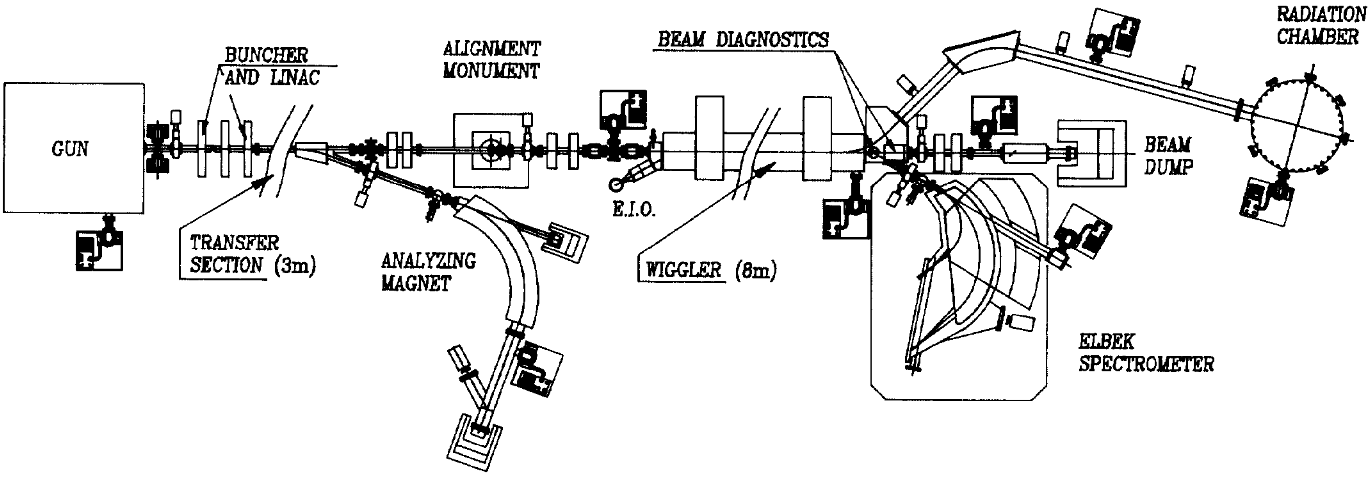

Fig.1 General layout of the experiment

The basic components of the ELFA project are:

- a RF linac delivering a 6 MeV electron beam with a peak current of 50 A;
- an electromagnetic wiggler of period 10 cm with a maximum peak dipole field on axis of about 3.6 kG;
- a microwave source (100 GHz) and a waveguide inserted in the wiggler gap in order to control slippage effects in the FEL;
- beam and radiation diagnostics to measure the energy spectrum and time structure of the electron and FEL radiation.

III. The Accelerator System

The linac consists of a gridded triode electron gun, a prebunching standing wave cavity at 1.3 GHz and a linac operating at 1.3 GHz to produce a 6 MeV electron beam. Details on the linac design are reported in other papers [8,9] presented at this Conference.

The beam line has been designed in a modular way to provide flexibility and it consists of three sections:

- the transport section to obtain electron beam waists in both the transverse planes;
- a matching section to adapt the beam to the wiggler;
- an analysing section to control on line the stability of the beam energy and energy spread.

IV. The Wiggler

Some additional parameters of the wiggler are listed in Table 2.

The wiggler period and gap have been chosen in such a way to satisfy the FEL resonance condition in all the different experimental setups, without achieving prohibitive working conditions for the power consumption and the saturation level in the iron.

Table 2. Main wiggler parameters

Type	DC iron core electromagnet
On axis gap	g = 4.0 cm
Harmonics content	< 1 %
Pole length	22.5 mm
Pole profile	Cylindrical (R = 160 mm)
Maximum current	300 A
Magnetomotive force/coil	3600 At
Total maximum power	P = 250 kW
Excitation pattern	1-2-2-2-1

The wiggler has been designed in order to produce an horizontal focusing of the electron beam in addition to the intrinsic vertical focusing. A transverse profiling of the pole surfaces[10] has been preferred with respect to external quadrupole focusing or pole canting techniques[11] because it is less disturbing for the FEL process. Finally, the global harmonics content has been reduced, by optimizing the pole length, to be lower than 1% of the fundamental, in order to maintain a high coupling between the field and the electron beam. A full scale, one λ_w, model (at λ_w = 12 cm instead of 10) has been built to test the theoretical predictions, based on analytical models and numerical 2D simulations, for the field strength and quality, the harmonics content and the transverse field distribution needed for focusing.

Fig. 2 shows the peak on axis field as a function of the current with and without PM assisting, compared with the 2D POISSON simulation results.

At the maximum nominal current (I = 300 A), where the pole iron begins to saturate, a peak field about 6% lower than the one obtained with the 2D POISSON code has been found. For this reason transverse pole tapering, in order to further reduce the power consumption and the saturation effects, will be carried out in the wiggler prototype.More details on this work can be found in Ref.[12].

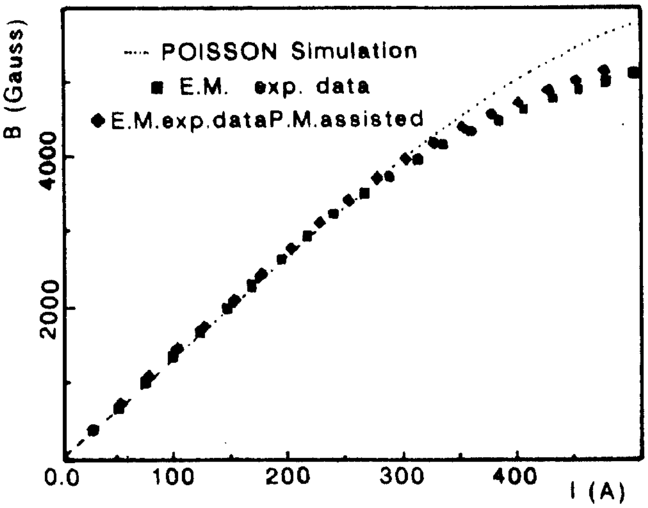

Fig. 2 Measured peak on-axis field as a function of current, compared to POISSON simulations.

V. Microwave generator and waveguide

The high gain FEL amplifier needs a 100 GHz master oscillator with enough power to trigger the FEL process and to maintain the saturation length shorter than the wiggler length. A commercial Extended Interaction Oscillator (EIO) at 100 GHz with a peak power of 1 kW, a mechanical tuning of ± 1 GHz and a maximum duty cycle about 1%, seems the most suitable solution.

The interaction structure, inserted in the gap of the wiggler, is a waveguide, whose large cross section is necessary in order to accomodate the transverse motion of the electron beam. An oversized rectangular waveguide can be used in the experiment also if this guiding system leads to some problems related to the control of unwanted high order modes, that are excited by the beam itself and by any waveguide discontinuity. For this reason another guiding system has been considered, the so-called groove guide, which is a typical low loss transmission structure in the 3 mm band. It consists of two parallel conducting planes, where two longitudinal grooves permit to trap a guided electromagnetic wave. The characteristics and properties of the groove guide are described in more details in a paper presented at this Conference[13].

VI. Electron and Radiation Diagnostics

Electron beam diagnostic would rely on the use of electromagnetic detectors, like strip-lines, which provide resolutions in position measurements up to tens of microns, and of image based systems. A lot of information about beam characteristics (profile, position with respect to pipe axis, transverse emittance, time structure) may be obtained placing on the beam path a material that gives a linear optical emission in response to the interaction of the beam and to look at the image through a camera. We started investigating fluorescent screen characteristics using a very low energy electron beam and developing a complete station for image acquisition and analysis. Horizontal and vertical profiles, transverse emittances (using the pepper pot technique) are automatically measured after an image of the beam has been taken. Real time display of the intensity distribution over the spatial coordinates of the beam may be displayed on a dedicated color monitor, to help the beam transport up to the wiggler.

The longitudinal profile of the beam would be studied using Cerenkov radiation analyzed using a streak camera which will give us resolutions up to 2 ps. Such a limit is well within the requirements before the beam experience FEL interaction. The energy distribution and the energy spread at the exit of the wiggler contain a quantitative description of the FEL interaction mechanism. To measure these quantities with a suitable resolution (0.1-0.2%) it is necessary to use a magnetic spectrometer with a large dispersion. A complete design of such a component has been carried out.

Microwave radiation average power would be measured using He cooled bolometers. Radiation pulse duration and time structure would be investigated by means of interferometric techniques.

VI. Conclusion

The ELFA project has been submitted to an international referee committee which gave a positive evaluation at the end of 1992. We are now waiting for the final approval and funding from INFN.

References

[1] R.Bonifacio et al., *Nucl. Instrum. and Methods*, **A289** (1990), 1;
[2] R.Bonifacio, L.DeSalvo, P.Pierini, N.Piovella, *Nucl. Instrum. and Methods*, **A296** (1990), 358;
[3] T.J.Orzechowsky et al., *Nucl. Instrum. and Methods*, **A250** (1986), 144;
[4] T.J.Orzechowsky et al., *Phys. Review Lett.*, **57** (1986), 2172;
[5] R.Bonifacio, L.DeSalvo, *Nucl. Instrum. and Methods*, **A276** (1989), 394;
[6] W.Schnell, *CERN-LEP-RF/88-59* (1988);
[7] E.Acerbi et al., *Proceedings of the 2nd European Particle Accelerator Conference*, Nice, June 1990;
[8] W.A.Barletta et al., "Design study for the ELFA linac", these Proceedings;
[9] G.Bellomo et al. "Design and test of prototype cavities for the ELFA linac", these Proceedings;
[10] E.T.Scharlemann, *J.Appl. Phys.*, **58** (1985), 2154
[11] K.E. Robinson, D.C. Quimby and J.L. Slater, *IEEE Journ. Quantum Electr.*, **QE-23** (1987), 1497
[12] E. Acerbi et al., *Proceedings of the 3rd European Particle Accelerator Conference*, Berlin, March 1992;
[13] P.Arcioni et al., "The groove guide: a non-conventional interaction structure for microwave FEL experiments", these Proceedings.