IL NUOVO CIMENTO Vol. 32 C, N. 2 Marzo-Aprile 2009
DOI 10.1393/ncc/i2009-10419-3

Colloquia: CSFI 2008

The PROMETEO Code: A flexible tool for Free Electron Laser study

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(ricevuto il 10 Settembre 2009; pubblicato online il 9 Ottobre 2009)

Summary. — Prometeo is a multi-particle code developed at ENEA within the framework of scientific programs aimed at studying and developing Free Electron Laser (FEL) sources. The code has been used either as a research tool to understand the dynamics of FELs operating in different configurations and as a practical tool to design FEL devices. In this paper we describe the structure of the code and its capability in describing either Oscillator and Single pass configuration. We compare Prometeo performances with those of other existing codes and finally comment on its role in designing high-gain devices as the SPARC source.

PACS `41.60.Cr` – Free-electron lasers.
PACS `87.16.A-` – Theory, modeling, and simulations.

1. – Introduction

The code named PROMETEO has been developed during the last twenty five years to model the physics of Free Electron Laser (FEL) [1] and it has been conceived as a flexible tool to deal with the wealth of configurations characterizing the FEL devices. The code has been developed either as study and design tool. One of its important by-products has been the development of a series of practical formulae aimed at providing a quick evaluation of the FEL performances be it operating in the SASE, Oscillator or Optical Klystron mode [2]. From the technical point of view Prometeo (the name stands just to denote its flexibility) was initially conceived as a macro-particle device for the solution of the Neil-Prosnitz equations [3]. The main efforts have been directed towards the understanding of 1-dimensional effects like pulse propagation in FEL oscillators and in high-gain SASE devices, including the spiking dynamics. In order to have a fast man-code interplay, we have deliberately omitted important, but time-consuming, three-dimensional contributions from electromagnetic and electron beam propagation. The latter have been taken into account by including them as longitudinal effects.

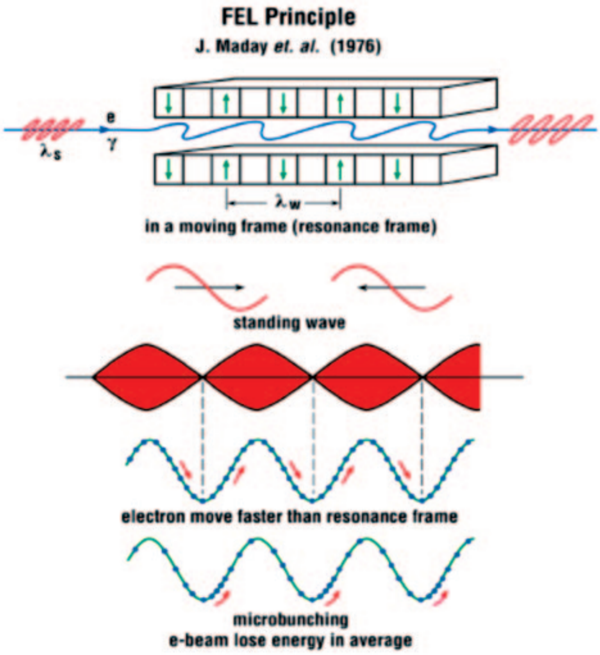

Fig. 1. – FEL amplification mechanism.

2. – FEL physics

In fig. 1 we have reported the FEL mechanism of amplification, in which a beam of relativistic electrons is injected in an undulator along with a coherent electromagnetic field, whose wavelength is nearly resonant with the radiation emitted by the electrons in the undulator. The electrons are captured in the standing wave formed by the two counter-propagating fields (the input and the undulator fields) and undergoes an energy modulation and a micro-bunching, at the scale of the seed field wavelength. The coherent emission, following the bunching, determines the amplification of the input field. In fig. 2 we show different ways to take advantage from the Free Electron laser amplification process. The first example is just an oscillator, in which the radiation spontaneously emitted in an undulator, is stored in an optical cavity and is reflected back to interact with a freshly injected electron bunch thus becoming amplified accordingly to the previously discussed mechanism, with the growth process continuing until the saturation occurs as in conventional lasers. If mirrors are not available to confine the radiation, as it occurs for extreme UV-X radiation, the single pass high-gain solution may be adopted. In this case a high-intensity electron beam drives the FEL power growth in long undulators in one pass only.

In fig. 3 we have reported the FEL high-gain conceptual scheme which is essentially a flow chart design paradigma for any FEL code dealing with SASE FEL dynamics.

We have already noted that the FEL gain (or amplification) mechanism is associated with micro-bunching, which may occur not only at the fundamental harmonic but also at higher harmonics, determining the coherent emission at the fundamental and at shorter wavelengths $\frac{\lambda_S}{n}$ (where $n = 2, 3$) (fig. 4).

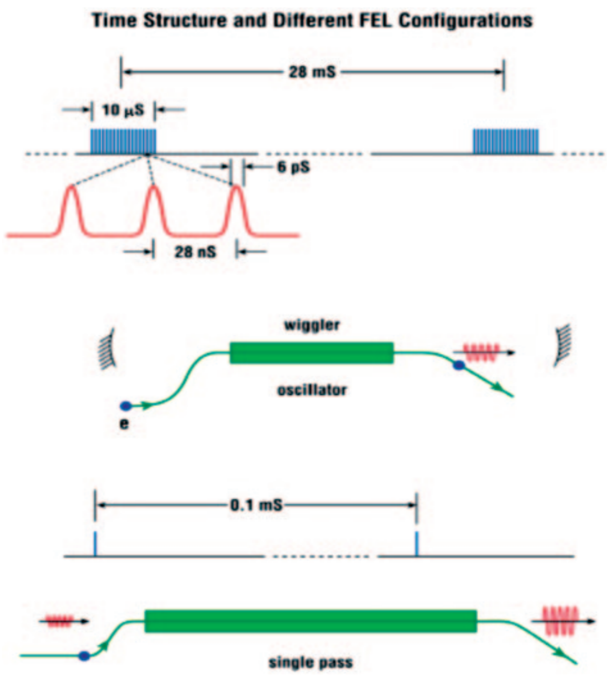

Fig. 2. – Oscillator and Single Pass FEL configurations.

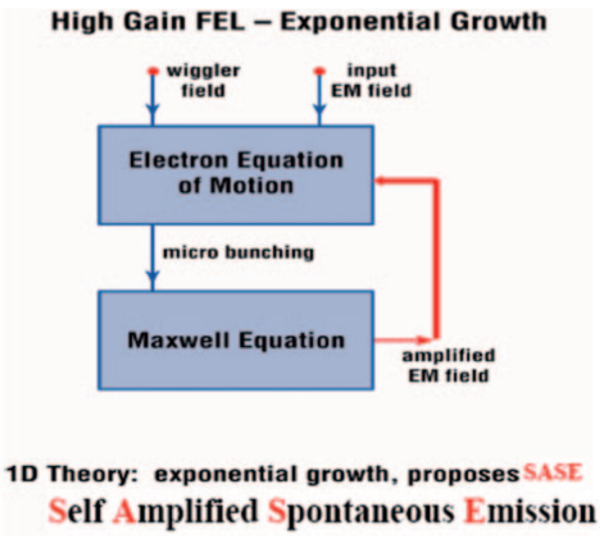

Fig. 3. – SASE FEL flow chart dynamics.

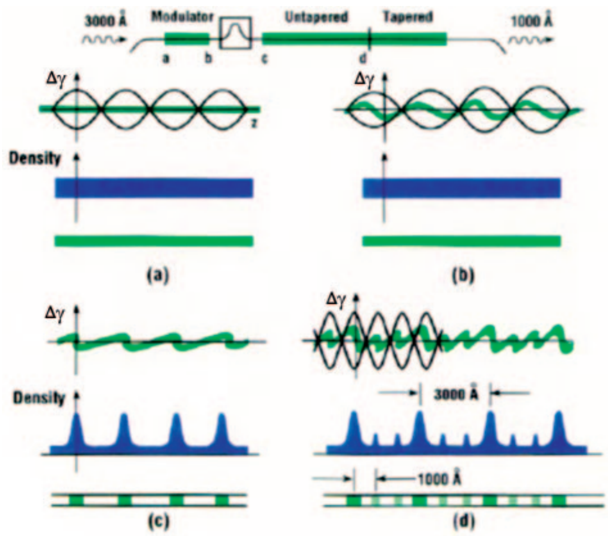

Fig. 4. – Bunching at higher harmonics and a scheme of FEL harmonic generation experiment.

3. – Code predictions

The code Prometeo is capable of modelling all the previously described FEL configuration and in the case of the oscillator may provide the results reported in fig. 5, showing the evolution, at different round trips in the cavity, of the fundamental and of the third harmonics.

In fig. 6 we have reported the power growth of a SASE FEL along the undulator coordinate, using the SPARC parameters [4]. The computation reports the fundamental

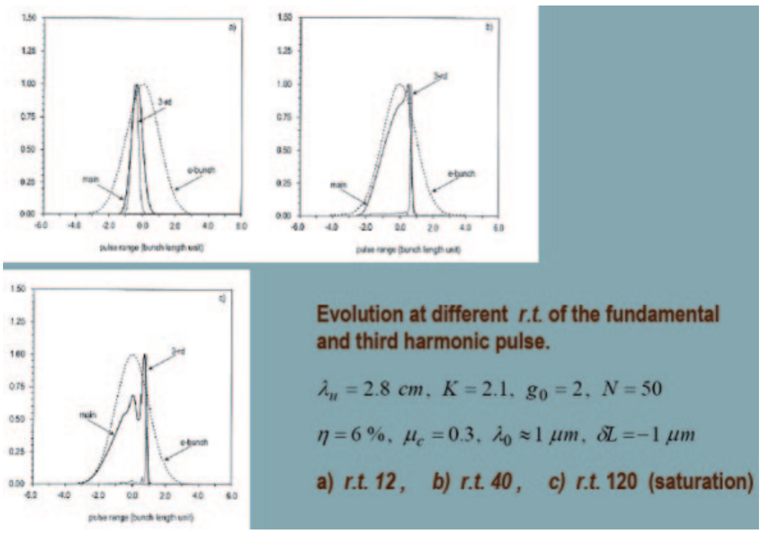

Fig. 5. – Intra-cavity evolution of a FEL oscillator operating at $1\,\mu$m.

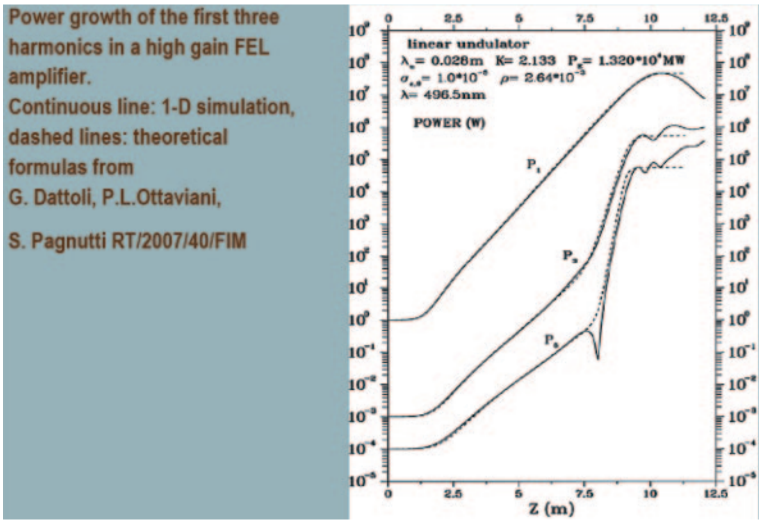

Fig. 6. – SASE FEL power evolution for the SPARC project.

and higher harmonics (the third and the fifth) along with a comparison (dotted line) with an analytical computation. The reliability of the code has been checked in different ways. By making, whenever possible, a comparison with the theory, with other available codes and with the experiment. The detailed comparison of its predictions with the SPARC experimental results has fully confirmed the reliability of PROMETEO.

REFERENCES

[1] Dattoli G., Galli M. and Ottaviani P. L., ENEA report RT/INN/93/09 (1993).
[2] Dattoli G., Pagnutti S. and Ottaviani P. L., Booklet for FEL design: a collection of practical formulae (Enea Edizioni Scientifiche) 2008.
[3] Prosnitz D., Szole A. and Neil V. K., *Phys. Rev. A*, **24** (1981) 1436.
[4] Dattoli G., Ottaviani P. L. and Pagnutti S., ENEA report RT/2007/40/FIM.