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M. Couprie et al

(M. Desmons, M. Jablonka, F. Méot, A. Mosnier)

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Département d'**A**strophysique, de Physique des **P**articules, de Physique **N**ucléaire et de l'**I**nstrumentation **A**ssociée

DSM/DAPNIA, CEA/Saclay F - 91191 Gif-sur-Yvette Cédex

Tél : (1) 69 08 24 02 Fax : (1) 69 08 99 89

http : //www-dapnia.cea.fr

Couverture : Sylvie Cabrit et Marc Sauvage

"ARC-EN-CIEL" A PROPOSAL FOR A 4TH GENERATION LIGHT SOURCE IN FRANCE

M. E. Couprie [1], M. Desmons[2], B. Gilquin[1], D. Garzella[1], M. Jablonka[2], A. Loulergue[3], J. R. Marquès[4], J. M. Ortega[5] F. Méot[2], P. Monot[1], A. Mosnier[2], L. Nahon[1], A. Rousse[6]

1-CEA Saclay (DSM/DRECAM), 2- CEA Saclay (DAPNIA/SACM), 3- Synchrtron SOLEIL, 4- LULI (Ecole Polytechnique, Palaiseau), 5-LURE (CNRS, Orsay) 6- Laboratoire d'Optique Appliquée (ENSTA, Palaiseau)

Abstract

An accelerator based 4th generation source is proposed to provide the user community with coherent femtosecond light pulses in the UV to X ray range. The project is based on a CW 0.7-1 GeV superconducting linac delivering high charge, subpicosecond, low emittance electron bunches with high repetition rate. A High Gain Harmonic Generation setup, seeded with high harmonics in gases, will cover a spectral range down to 0.8 nm. SASE Radiation will also be provided down to 5 nm. In addition, two beam loops are foreseen either to enhance the energy to 1.4-2 GeV or to increase the beam current in using the energy recovery technique. They will accommodate fs synchrotron radiation sources in the IR, VUV and X ray ranges together with a FEL oscillator in the 10 nm range. Main features of the project and scientific goals are given.

INTRODUCTION

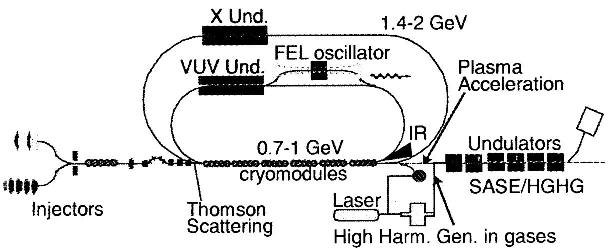

Fig. 1 : Schematic of ARC-EN-CIEL layout

Short pulses Free Electron Laser (FEL) in the VUV-soft X ray spectral range seem very attractive sources for time-resolved studies in various scientific domains [1]. France developed different FEL devices, starting with the first storage ring Free Electron Laser on ACO [2] in 1983, the UV FEL on Super-ACO [3] and the Linac based Infra-red FEL user facility CLIO in 1992 [4]. First time-resolved pump-probe two color experiments were perfomed, using the Super-ACO UV FEL and synchrotron radiation [5].

A new independent accelerator based radiation facility is proposed, *ARC EN CIEL* (Accelerator-Radiation Complex For Enhanced Coherent Intense Extended Light), aiming at providing tuneable, adjustable polarisation, coherent femtosecond light pulses in the UV to X ray range for scientific applications. In this project, a full dedicated integration of conventional, high power, laser sources is foreseen, from the electron beam generation in the photoinjector to the laser seeding in the insertion devices and the synchronization with the accelerator based light sources for users applications in pump-probe two-colour class of experiments.

THE *ARC-EN-CIEL* LAYOUT

The accelerator

The linac has been devised to deliver a 1 mA, 700 MeV to 1 GeV electron beam in one pass. The TESLA superconducting technology has been taken as a design basis, i.e. cryomodules composed of 8 9-cell, 1.3 GHz cavities. Cavities quality factor Q_0 has been assumed equal to 10^{10}. A 15 MV/m accelerating gradient in the 1.04 m long cavities has been found to lead to a good compromise between linac cost and cryogenic plant power. As a result, 6-8 modules are required. We choose to power the cavities in using a 100 kW CW klystron as the one that has been built and tested at JLab [6], though at a slightly different frequency. 12 klystrons, supplying 4 cavities, are then required. With the above parameters power dissipation is 23.5 W per cavity. We have estimated then at 1.5 kW the required cryogenic plant capacity. The bunch compression scheme yet though will aim at providing electron bunches in the 200 fs RMS range.

Table 1: Linac main characteristics

	Linac	
Energy	MeV	700
Length	m	72
Injection energy	MeV	10
# of modules		6
# of klystrons		12
Klystron power	kW	100
	Cavities	
# of cavities		48
RF frequency	GHz	1.3
Length	m	1.04
Q_0		10^{10}
Q_{ex}		10^7
	Beam	
Bunch charge	nC	1
Emittance	m.rad	2.10^{-6}

It is then foreseen to build 2 recirculation loops that will be used either to reaccelerate the beam to increase its energy at a reduced current or to recover its energy at an increased intensity (ERL scheme). Loops length will have to be adjustable so that bunches return in accelerating or decelerating phase at the linac entrance. Energy recovery is of interest if the average beam current is high enough.

With 1 nC bunches, a frequency of 1 MHz is required for a 1 mA current. This will only be possible when a superconducting RF gun [7] will be available. Before that, we envisage using normal conducting RF guns, either delivering 10 MHz bunch trains, 800 µs long at 10 Hz like TTF or 1 kHz bunches in a CW scheme. These two options correspond to the double injector scheme represented in fig. 1.

Light sources

The very low transverse emittance electron bunches are injected in several undulator sections for generating coherent light either as Self Amplified Spontaneous Emission (SASE) in the 200- 7 nm range and for High Gain Harmonic Generation (HGHG) [8] in the 100-0.8 nm range, in particular starting from coherent harmonic generated in gases (HHG) at 20 nm [9]. In this innovative design, the seeding with HHG allow the spectral range to be extended towards the very short wavelengths in a much more compact device as compared to a simple SASE scheme, by offering a better longitudinal coherence thank to the seed coherence properties [9].

The two optional loops, for Energy Recovery or energy enhancement, will host insertion devices for the production of femtoseconds synchrotron radiation in the VUV and X ray ranges, together with a FEL oscillator

providing radiation down to 10 nm, taking advantage of the optical development for lithography. Infrared radiation will be produced by the edge magnet field, or with THz coherent Radiation [10]. The facility also proposes to test plasma acceleration and to provide a Thomson radiation source.

ARC-EN-CIEL PHASE-I

ARC-EN-CIEL phase-I aims at addressing technical difficulties and at gaining more experience before the construction of the whole project. This project also calls for an early involvement of potential users for defining a specific program prior to the final scientific case. It will be installed in the former Saclay Linac (ALS) where a 200 m long tunnel and adjacent hall, as well as two large user rooms are available.

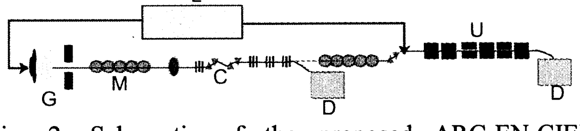

Fig. 2: Schematic of the proposed ARC-EN-CIEL prototype. G: RF gun; M: cryomodule; L: Laser System; C: compression chicane; U: undulator; D: beam dump.

The Accelerator

The phase I accelerator system includes a RF gun (PITZ type, but operating at 1 Khz) injecting directly into a module followed by a 3rd harmonic cavity to linearize the energy-phase correlation before a bunch compression chicane, a second module and the undulator for SASE and HGHG experiments. With a 15 MV/m gradient, a beam energy close to 250 MeV should be reached.

With respect to the TTF1 scheme [11], R&D studies on the 100 kW CW klystron type and the low level RF and amplitude-phase regulations will be carried out, along with thermal performances of main RF couplers, HOM couplers, helium circuits. The design of the cryomodules will be optimised for CW soft X-ray FEL sources, with less mechanical constraints as for TESLA. The magnetic chicane is of the "S" type as proposed in [12].

Table 2 gives the results on simulations performed with codes ASTRA and Trafic4 [13], assuming a TTF2 type gun, 15 MV/m gradients in the cavities, and a R_{56} compaction factor of 0.1 m in the chicane [14].

Table 2: Expected performances of the prototype machine

Charge	**nC**	**1**	**0.1**
Energy	MeV	220	220
Energy spread	MeV	2	0.5
Bunch length (rms)	fs	300	60
Emittance (normalized)	mm.mrad	1.7	2.1

We intend to use the TTF2 gun [15] that has been thoroughly tested at the PITZ facility and make it work in the CW regime of one bunch per 1 kHz RF pulse. All the power dissipation in the gun cavity will take place during RF filling and falling times. In its present status the gun cavity is reported [16] with a maximum capacity of dissipation of 27 kW and a quality factor of 23000. Thus, 3 MW peak are required at the input to obtain 40 MV/m on the cathode required for a satisfactory emittance. The 5 MW TTF klystron [17] can be used. In assuming then that 4 MW are available at the cavity input, the 3 MW level is reached exponentially with a time constant τ given by

$$\tau = \frac{\tau_0}{1+\beta}$$

where τ_0, the cavity time constant, is 5.6 µs and β the coupling factor, here equal to 1. Integration during filling and falling times gives a dissipated power of 12.9 J [18]. The gun is therefore able to work up to 2 kHz in this regime.

The dissipation during falling time can be reduced if the RF phase is shifted by 180° after the bunch passed. The cavity time constant can be reduced in increasing the coupling factor. An optimum is found with β=1.9. The gun could this way work up to 3 kHz.

Laser System

An integrated laser system will be used for both the electron beam generation onto the photocathode and the seeding in the undulator. A visible laser-pumped Ti-Sa oscillator, delivering 6-10 nJ at around 60-70 MHz will feed two amplifier systems, equipped with Chirped Pulse Amplification set-up. Both systems will operate at 1 Khz and will be naturally synchronized. R&D studies will be performed for keeping the mutual jitter to less than 10 fs.

The photocathode arm will be optimised for delivering 100 μJ, 10 ps long pulse at a wavelength of 266 nm. Special effort will be devoted to the implementation of an acousto-optical programmable dispersive filter [19] for the longitudinal pulse shaping, in order to obtain very short edged (0.5 ps) flat-top electron pulses. This will help to reduce further the beam emittance. Deep characterization of the laser pulse via SPIDER (Spectral Phase Interferometry for Direct Electric-field Reconstruction) techniques [20] is foreseen. The seeding arm is intended to deliver between 10 μJ and 2.5 mJ in a 50 fs long pulse, in the 160-800 nm spectral range.

FEL Sources

The AEC-Phase I project aims at being a test facility with a strong synergy between accelerator physicists and all the potential users. According to this, the goal for this first phase is already to test the VUV-XUV coherent light source generation by use of the High Gain High-order Harmonic Generation (HGHG) technique, in which a coherent beam seeded in a two undulator (modulator plus radiator) setup will act as the buncher to be either amplified or frequency up-converted. Table 3 provides the undulators main characteristics;

Table 3: HGHG Undulators characteristics

Und.	Modulator	Radiator
λ_R (nm)	267/200	89/66
λ_U (cm)	38.9	20
K	1.76	1.14
No. of periods	34	450

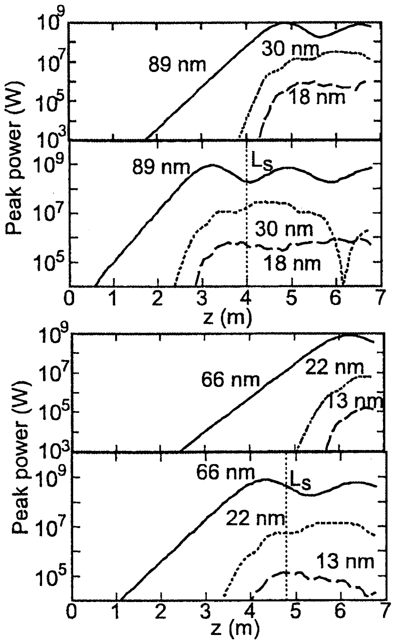

Fig. 3: Peak Power vs radiator length in the HGHG configuration. L_s represents the saturation length.

One of the innovations, calling for R&D studies, is given by the use as seeding of an integrated system including Ti:Sa laser, Optical Parametric Amplifiers (OPA) and High Order harmonics generated in gases, thus allowing to continuously span the seeding wavelength from the IR (800 nm) to the VUV (160 nm).

This will allow to generate coherent radiation in the VUV-XUV range down to 20 nm. Fig; 3 shows some preliminary results obtained with the 0-D code PERSEO [21], developed at ENEA. AEC Phase-I HGHG system is seeded with a 175 KW peak power laser pulse at 266 and 200 nm, respectively. The output FEL peak power is shown as function of the longitudinal position in the radiator undulator for the 3rd, 5th and 7th harmonics of the seeding pulse. The saturation is achieved much more rapidly in the HGHG case than in the SASE one. In addition HGHG radiation is fully coherent. Besides, Non Linear Harmonics are also available. This radiation will be exploited by users. A deeper insight on the used methods for simulations and further results are shown in [22].

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REFERENCES

[1] H. Wabnitz et al, Nature 482 (2002)
[2] M. Billardon et al, *Phys. Rev. Lett.* 51, 1652 (1983)
[3] M. E. Couprie et al., *Phys. Rev. A* . 44(2), 1301-1315 (1991)
[4] R.Prazeres et al *Phys. Rev. Lett.* 78(11), 2124-2127 (1997)
[5] M. Marsi et al., *Appl. Phys. Lett.* 70 (1997), 895-897
[6] S. Lenci, et al. "Recent Progress in CW Klystrons at CPI", EPAC 2002, Paris
[7] V.N.Volkov, "Generation of Sub-Picosecond Electron Bunches in Superconducting RF Photocathode Injector", PAC 2003, Portland
[8] L.-H. Yu et al Science 289, 2000, 032
[9] P. Salières et al., Adv. At., Mol., Opt. Phys. 41, 83 (1999) and references therein.
[10] Workshop IRSR (1998), Proceedings ed. LURE
[11] P.Castro, "Performance of the TESLA Test Facility Linac", EPAC 2002, Paris
[12] A. Loulergue, A. Mosnier, "A Simple S-Chicane for the Final Bunch Compressor of TTF-FEL", EPAC 2000
[13] K. Flöttmann, "ASTRA User Manual", www.desy.de/~mpyflo/Astra documentation
Traffic4, M. Dohlus et al., http://www.slac.stanford.edu/~akabel/TraFiC4/
[14] A. Loulergue, "Simulations ARC-EN-CIEL phase 1", alexandre.loulergue@synchrotron-soleil.fr
[15] B. Dwersteg et al., "RF gun design for the TESLA VUV Free Electron Laser", NIM A 393 (1997) 93-95
[16] J. Baehr et al., "Behavior of the TTF2 RF Gun with long pulses and high rep. rates", TESLA rep. 2003-33
[17] THALES, klystron TH2104C, www.thalesgroup.com
[18] M. Desmons, Note Interne, mdesmons@cea.fr
[19] P. Tournois, Opt. Comm. 140, 245 (1997)
[20] J.Biegert et al., Optics Letters 28, 281-283 (2003).
[21] L. Giannessi, http://www.afs.enea.it/gianness/perseo/
[22] G; Lambert et al., this Conference Proceedings.