FIRST ELECTRON BEAM MEASUREMENTS ON COXINEL

T. André, I. Andriyash, C. Basset, C. Benabderrahmane, P. Berteaud, S. Bonnin,
F. Bouvet, F. Briquez, L. Cassinari, L. Chapuis,M. E. Couprie, Y. Deitriech, D. Dennetière,
C. De Oliviera, J. P. Duval, M. El Ajjouri, T. El Ajjouri, P. Gattoni, C. Herbeaux, N. Hubert,
M. Khojoyan, M. Labat, N. Leclercq, A. Lestrade, A. Loulergue, O. Marcouillé, F. Marteau,
P. Pierrot, F. Polack, F. Ribeiro, J.P. Ricaud, P. Rommmeluère, M. Sebdaoui,K. Tavakoli,
M. A. Tordeux, M. Valléau, J. Vétéran, D. Zerbib, Synchrotron SOLEIL, Saint-Aubin, France
S. Bielawski, C. Evain, C. Szwaj, PhLAM/ CERLA, Lille, France
E. Roussel, FERMI@ELETTRA, Sinctrone Trieste, Basovizza, Italy
J. Gautier, E. Guillaume, K. Ta Phuoc, G. Lambert, B.Mahieu, V. Malka,
A. Rousse, C. Thaury, Laboratoire d'Optique Appliquée, Palaiseau, France

Abstract

The ERC grant COXINEL aims at demonstrating experimentally Free Electron Laser (FEL) amplification with electrons generated by laser plasma acceleration (LPA). Because of the still limited electron beam performance (especially energy spread and divergence) in view of the FEL requirements, the electron beam transfer line has been specifically designed with adequate diagnostics and strong focusing variable strength permanent magnet quadrupoles, an energy de-mixing chicane and second set of quadrupoles for further dedicated focusing in the FEL interaction region, in a U20 in-vacuum undulator, enabling to operate at 200 nm with a 180 MeV electron beam. The first observation and transport of electrons in the COXINEL line is presented here.

INTRODUCTION

In the laser-plasma acceleration (LPA) technique, a short multi-TW laser pulse propagates through a gaseous medium and drives strong plasma waves in its wake [1, 2]. The electric fields of these plasma waves can exceed the ones generated in the conventional linear accelerators by few orders of magnitude. LPA electron beam have been accelerated to high energies on a mm scale, but the transverse components and longitudinal gradient of these plasma fields produce significant dispersion of electron transverse and longitudinal momenta. As a result, while todays LPAs deliver femtosecond beams of MeV-GeV electrons with kA currents, the transport and beam manipulations [3–8] required for FEL application remains very challenging. So far LPA based undulator radiation has been observed [9–13]. Among others projects [14, 15] COXINEL aims at using a LPA to drive an FEL, taking advantage of a specific design of the transfer line to handle divergence and energy spread.

COXINEL DESCRIPTION

In the COXINEL experiment, the "Salle Jaune" laser system of Laboratoire d'Optique Appliquee (LOA) is used and delivers a 30 fs, 30 PW beam to the interaction chamber, where it is focused into a spot of 10-15 µm size. For LPA, a supersonic flow of a gas mixture composed of 99% of Helium and 1% of Nitrogen is produced by a millimeter scale nozzle. In such a setup electrons are injected into the laser wake via ionization injection mechanism [16]. This method of production creates a high divergent beam (≈ 1 mrad) with a wide energy spectrum (150 MeV to 250 MeV). Three permanent magnet quadrupoles, so called QUAPEVA, of variable gradient (up to 200 T/m), placed near to the source inside the production chamber focus strongly the beam. The electrons go through a first steerer (generating a field of 350 G at 10 A). The electron beam passes in a demixing chicane (see Table 1) for sorting the electrons in energy [17, 18]. Then they enter in a second steerer, before a set of four electromagnetic quadrupoles (see Table 2).

Table 1: Characteristics of COXINEL Dipoles

Characteristic	Unit	Value
Gap	mm	25
Yoke length	mm	200
Current	A	150
Current density	A/mm^2	2
Magnetic field B @ 150 A	T	0.55

Table 2: Characteristics of the Quadrupoles

Characteristic	Unit	Value
Maximum gradient	T	20
Bore diameter	mm	24
Current	A	10
Current density	A/mm^2	1.6

The electrons then go through an in-vacuum hybrid permanent magnet U20 undulator (see Table 3) surrounded by two steerers and two cavity BPMs from SwissFEL (see Fig. 3). A chromatic matching enables to synchronize the focus of the electrons slices with the progress of the optical waves to ensure a maximum electronic density over the undulator length [19].

Two integrating current transformers (ICT) from BERGOZ, for electron beam charge measurements are located after the QUAPEVAs in the electron generation chamber and at the exit of the undulator (see Fig. 3).

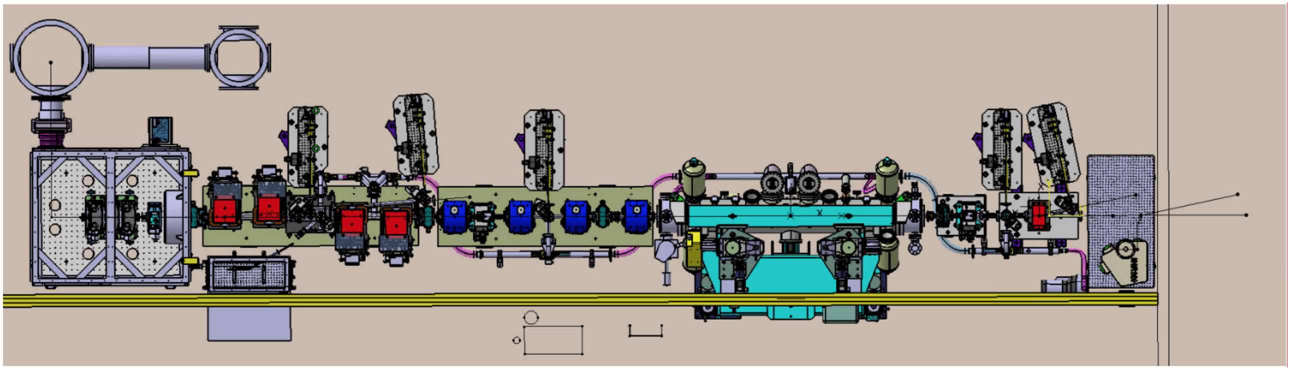

Figure 1: CATIA general integration view of the COXINEL LWFA demonstration set-up (from left to right) : LWFA chamber (grey) with the first set of quadrupoles and a current beam transformer, magnetic chicane dipoles (red), quadruplet of quadrupoles (blue), undulator (case of 2 meter U20 undulator), dipole for beam dump (red), spectrometer (brown).

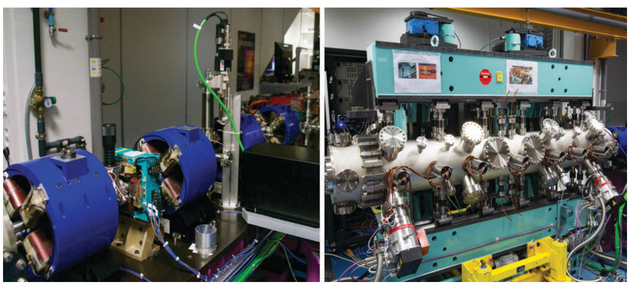

Figure 2: Left : quadrupole (dark blue) with steerer (light blue) and screen arm support. Right : U20 Undulator

Table 3: Characteristics of the U20 Undulator

Characteristics	Unit	U20
Period	mm	20
Technology		Under Vacuum
Permanent magnet		$Nd_2Fe_{14}B$
Poles		Vanadium-Permendur
Number of periods		98
Minimum gap	mm	5.5
Peak field	T	1.5
Magnetic length	m	2

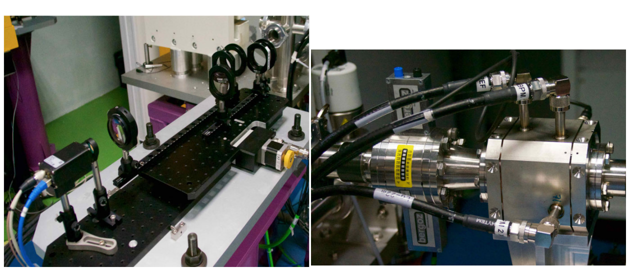

Figure 3: Left : Optical setup for imagers. Right: ICT 2 (left) and cBPM 2 (right) at the exit of the undulator.

There are also five imagers on the line. Different screens (YAG, LANEX, OTR and target for calibration) of 1” size, mounted on a motorized arm at 45°, intercept the beam. The extracted light through a window is imaged via lenses onto a CCD camera (Basler SC640-GM). Imager 2 and 3 are placed in the middle of the chicane off-axis for energy and energy spread measurement.

The photon diagnostics at the end of the beam line include a photomultiplier (Hamamatsu), a spectrometer (Horiba) and a camera for imaging the inside of the undulator.

The vacuum system is composed by a primary circuit all along the line and six turbomoleculars pumps at different locations (two on the dipole girder, one on the quadrupoles girder, two on the undulator and the last one at the end of the line). The vacuum in the line is about 10^{-5} mbar whereas in the generation chamber, it is a few 10^{-3} mbar.

The control is managed through the equipments device servers by TANGO system, similar to the one used at synchrotron SOLEIL. Motors are moved via XPS (Newport) controllers. Compact PCI are used for ICT, cBPMs and spectrometer. Several high level applications (machine configuration, machine status, vacuum, imagers etc.) have been developed in Matlab and Python. In addition to the two power supplies cabinets, there are additional ones for the magnetic elements and the control server, vacuum and diagnostics.

INSTALLATION

Each different piece of equipment has been characterized independently and installed on its girder prior to installation on the LOA site. The reference axis has been aligned using a laser tracker (Faro) on the LOA site. Fiducial references were taken for the magnetic elements on the magnetic measurement benches and reported on the LOA site. The installed line is shown in Fig. 5.

FIRST TRANSPORT THROUGH COXINEL BEAM LINE

The electron beam is first generated and tuned without the QUAPEVA quadrupoles installed. A specific dipole can be used to check the energy range of the electrons. Various adjustments can take place such as the laser direction and focus spot, the gas pressure etc. Then, the first QUAPEVA

ISBN 978-3-95450-147-2

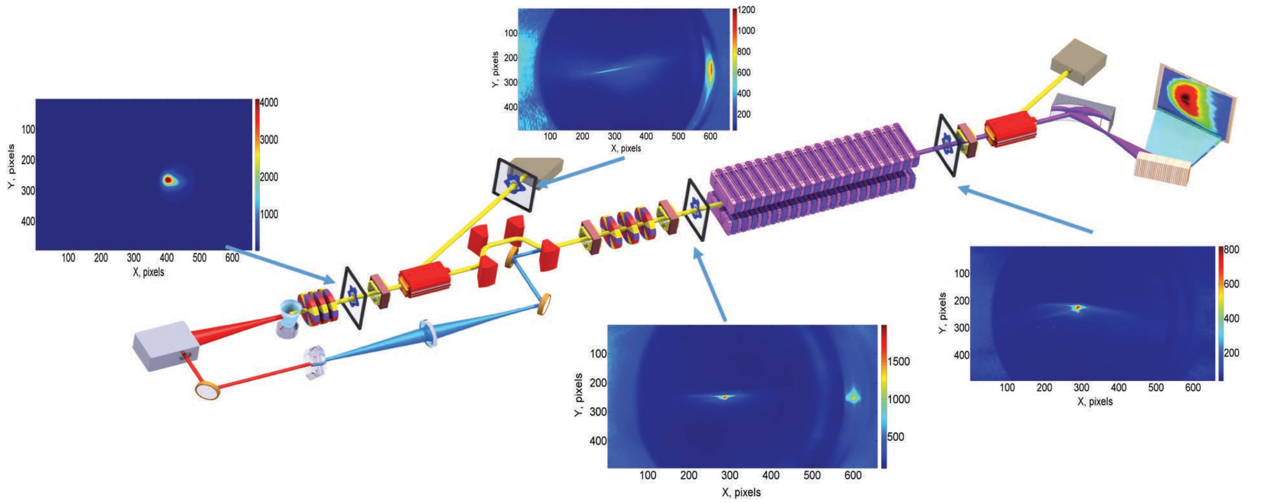

Figure 4: Beam propagation along the line. From the left to the right and top to bottom, the beam seen on imager 1, 2, 4 and 5 respectively (1 pixel is equivalent to 32 µm).

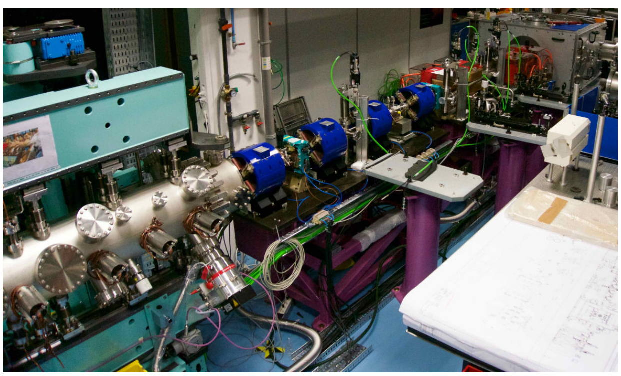

Figure 5: The COXINEL beam line installed in "Salle Jaune".

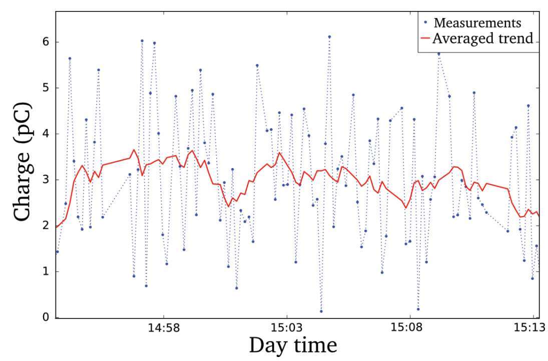

Figure 6: ICT 2 trend during a 20 minutes laps time with undulator gap closed at 10 mm. In blue the charge measured shot to shot and in red the mean charge over a 10 shots sliping window.

is installed and its alignment (previously set with the laser tracker from the reference taken at the magnetic measurement bench) is checked with the electron beam. Then, the two other QUAPEVA are installed and checked one after the other, using the first electron imager located in the electron generation chamber. In order to transport further, the electron beam can be observed using electron deflection performed with the dipole of the chicane. Then, step by step, the electron beam can be transported all along the line, as illustrated in Fig. 4. with recorded images at the different screen locations. The first transport has been performed with the undulator gap open at 10 mm, providing natural vertical focusing. With a proper transport and synchronisation, the ICT and cBPM could then be commissioned. Further transport has then been performed while closing the undulator gap down to 5.5 mm, applying the feedforward correction tables determined during the magnetic measurements, in order to correct from the residual field integrals. A charge up to 35 pC has been transported at the exit of the line. Figure 6 illustrates an example of a 3 pC transported charge evolution in time recorded during 20 min with 0.1 Hz repetition rate.

CONCLUSION

The COXINEL LWFA-FEL line is installed, and the first tests with the beam were performed. The LPA electron beam have been successfully recollimated and transported through the line. These preliminary results are encouraging for the pursuit of this development.

ACKNOWLEDGEMENT

The authors are grateful to the support from the European Research Council for COXINEL (340015) and X-Five advanced grants (339128), the French- Swedish collaboration for the support on the U15 cryo-ready undulator, the "Triangle de la Physique" for the QUAPEVA valorisation contract and to J. L. Lancelot, F. Forest and O. Cosson from Sigmaphi for their involvement in the project.

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ISBN 978-3-95450-147-2