GAMMA - RAYS AND X-RAYS PRODUCTION FOR EXPERIMENTS AT ELSA FACILITY

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Abstract

The ELSA facility is a high brightness 18 MeV electron source dedicated to electron irradiation, γ-rays and picosecond hard and soft X-rays. It consists of a 144 MHz RF photo-injector producing short bunches which are further accelerated to an energy varying from 2 to the maximum energy of 18 MeV thanks to three 433 MHz cavities. Former beam compression design used a half turn magnet compressor system. It was recently replaced by a double alpha magnet compressor. Electron beams are now delivered to a new experimental room. We present the new panel of interests offered by this facility in terms of short pulses X-ray production.

INTRODUCTION

The ELSA facility was designed in the late 80's, as a test bench for physics and technology of high efficiency FELs [1]. It consists of a RF photo-injector followed by a linear accelerating structure, a compressor magnet and adapted undulators. After the demonstration of free electron laser operation in the IR range was completed, improvements of the accelerator were needed. Main concerns were on the cavity of the photo-injector and on the stability of the laser system. A renewed cavity was built to fit with ultra high vacuum for photo-cathode life time requirements (10^{-10} mbar is the typical vacuum pressure at present time). The pulse-to-pulse fluctuations of the drive laser which can operate at either 532 nm or 236 nm, depending upon the choice of cathode type, were also solved. In response to new needs, the facility is now mainly used as a high-brightness electron source or as a picosecond hard X-ray source via bremsstrahlung on high Z materials. Due to lack of room to set the experimental devices in the former facility, a contiguous experimental area has been added. In order to achieve short pulses a magnetic compressor was re-design. It is now made of two alpha-magnets type (with field index of 1) [2]. The beam is also tightly radialally focused on production targets. In this ELSA2 facility, new dedicated beam lines built in this experimental area, are now commissioned. This allows to users a panel of versatile experimental conditions with short pulses of electrons, X-rays or γ-rays.

ELSA FACILITY

The ELSA overview facility is presented on figure 1. It is made of a 144 MHz photo-injector delivering for nominal operating conditions, trains of electron bunches at 2.5 MeV. The temporal structure consists of macropulses of 20 to 150µs duration. Maximum repetition rate is 10 Hz. A macropulse is made of 20 ps long micropulses (individual bunch) at a repetition rate of 14.4 MHz (see figure 2). The acceleration is completed by three 433 MHz accelerating cavities. These cavities operate at room temperature. The photo-injector cavity is powered by a tetrode tube supplying 1.5 MW of peak power. This gives an accelerating gradient of 30 MV/m.

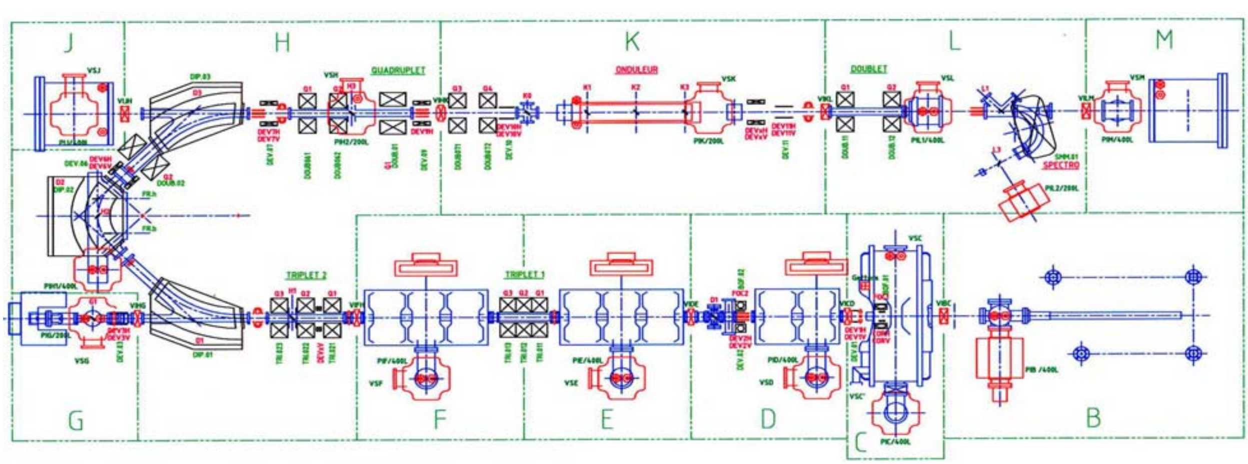

Figure 1: Former overview of the ELSA facility: room size is 12 m x 5 m and beam is bent to 180 ° through a half turn compressor magnet system made of three dipole magnets.

The 433 MHz accelerating RF cavities are powered by a unique klystron (TH2118) for which peak power of 6MW is split between the cavities. Focusing elements (solenoids at the extraction, quadrupole triplets further downstream) and a set of steering coils provide the proper beam transport tuning through the overall structure. For the benefit of experimenters, any beam energy value is easily obtained starting at 2 MeV at the expenses of some beam quality for low energies. Routinely, 20-30 ps duration laser pulses (FWHM) shining a 6 mm diameter photo-cathode permit to extract a charge of 5 nC per bunch. Two types of cathodes K_2CsSb and Cs_2Te depending upon the laser wavelength operating choice can be used. The bunch absolute charge is measured at 4 different locations along the beam propagation. As instance, G1(see figure 1) stands for the Faraday cup measurement location.

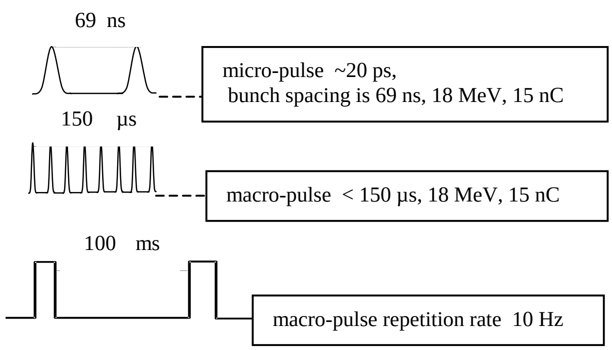

Figure 2: Typical train of bunches.

For some studies the charge contained into a single bunch can be raised as high as 50 nC. Bunch pulse is longer in this case (200 ps) [3], but 15 nC is a more usual extracted charge value corresponding to 60 ps bunch durations.

TRANSVERSE AND LONGITUDINAL PHASE SPACES QUALITIES

Measurements of the beam phase space showed that, at low charge (1nC, 60 ps), the transverse normalized rms emittance is as low as 1 µm, very close to the theoretical thermal emittance value of RF guns emittance [4]. The ability to accelerate such high bunch densities while maintaining small emittance values , is a direct benefit of the low frequency operation of the RF accelerating cavities.

This transverse emittance is measured at G1 location by means of the quadrupole scanning technique (beam transverse profiles are measured by OTR screens while acquisition is made with an intensified CCD camera [5]. Normalized measured rms emittance for a bunch carrying 10 nC is 2.5 µm.

The electron bunch and drive laser temporal pulse lengths and shapes can be simultaneously measured ahead and after the bend thanks to a synchroscan streak camera. Whilst at 5 nC the bunch length is still close to the 60 ps time duration of the driving laser pulse value, due to space charge effects it lengthens to 65 ps for 10 nC and to 90 ps for 15 nC [5].

ELSA LAYOUT

Figure 3 shows the ELSA2 experimental area layout.

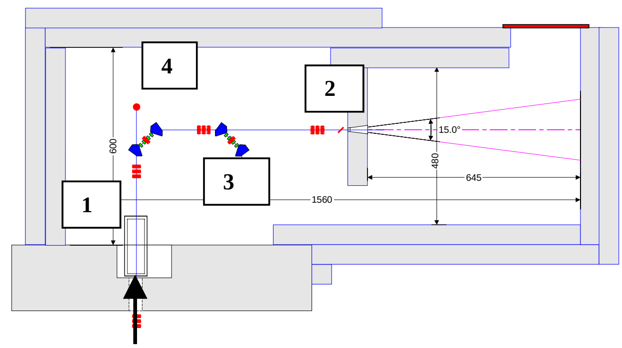

Figure 3: New experimental area (~80 m^2). On this figure the electron beam comes from the bottom (shown by the arrow).

The aim of the entire project was also to upgrade the beam energy after the beam has been compressed down to a small value of ~10 ps [6]. A post acceleration given by a 1300 MHz RF accelerating structure is intended to boost the energy up to 40 MeV. Only the first part of the ELSA 2 project has been commissioned but this latter phase has been postponed. At the end of the linac, the electron beam crosses a thick wall which separates the main accelerator room from the experimental area. It is then compressed (the compressor which deviates the beam vertical is not visible on figure 3).

After compression, the beam can be distributed to 4 different locations (schematically shown on figure 3 .

The beam lines have specific features.

Beam line 1 for which the beam goes straight can handled high intensity beams dedicated to high bunch intensity measurements (spot size measurements, dose, X-ray imaging, direct irradiation by electrons)

Beam line 2 is mainly used for γ-ray production from bremsstrahlung interaction on a thick target (labelled T on figure). The photon beam is collimated whereas electrons are damped. Large room behind the production target is provided to house X-ray imaging experiments.

Beam line 3 will be dedicated to low back ground or high average intensity experiments

Beam line 4 belongs to the phase 2 of the project where a Thomson source is to be built.

IRRADIATION AREA

The electron beam from beam line 1 can be used either for beam dynamics studies or direct irradiation by electrons. Beam dynamics involves the handling and behavior of high charged bunch beams and final radial focusing to tight spot size. These studies are related to a project called RX2 where a RF linac coupled to a photo-injector is proposed as a new versatile radiographic machine. Irradiations by electrons in the 800 keV - 2.5 MeV range are also of great interest for precise calibration of displacement energy measurements in irradiated materials. Studies on the evolution of the electrical resistivity of material samples under irradiation have been also carried out.

γ-RAY PRODUCTION

As mentioned previously, beam line 2 delivers bunched electron beam to a bremsstrhalung production target. A large room, well hardened against parasitic radiations, is used for X-ray imaging experiments. Calibration of impulse response of CdTe detectors as X-ray diagnostics for the future carries on. Also, it is a test facility for fission chambers developments dedicated to measurement of cross sections in photo-fission reactions. Yield point against high electron fluxes for mechanical strength is still an issue for such developments in view of measuring the temporal distribution of delayed neutrons in photo-fission reactions.

SOFT X-RAY PRODUCTION

The possibility to use an electron linac as a driver for an X-ray transition radiation source (XTR) has been considered both on theoretical and experimental aspects for several years. At the ELSA facility soft X ray pulses as short as 10 to 20 ps, in the energy range 0.5 to 2 KeV, can be produced by means of this process [7]. In many experiments as plasma physics, fluorescence measurements, exploration of atomic processes involved in plasma physics, temporal investigation of physical property of matter, the continuous aspect of a X-ray source issued from synchrotron radiation is useless despite the high photon flux since only single-pulse mode operation is of interest for those special applications. As far as photon brightness is concerned, even if it cannot compete with synchrotron radiation sources, a photo-injector driven linac X-ray source makes sense for these specific fields. The production target design stays a key issue in order to achieved enough signal. Proper designs include the foil stack and the multi-layer arrangement. A demonstration experiment has been carried out to consider the possibility of installing such a soft X-ray source on the ELSA facility. Very encouraging results were obtained, but too much of background noise due to the environment imposed a re-design of the production set up. Beam line 3 is intended to reactivate this X-ray production source thanks to its low back ground design .

THE THOMSON SOURCE PROJECT

Several groups have demonstrated proof-of-principle generation of soft X-rays in the keV range through interaction of picosecond or femtosecond laser with MeV electron beam in collinear or orthogonal geometry [8]. Taking advantage of the ELSA low emittance electron beam and of the synchronous drive laser for which the energy would be amplified to 100 mJ for this use, an experimental demonstration could be carried out as a first step at 20 MeV. In a second step, energy upgrade to 40 MeV is expected to enhance the performances of such a source (brigthness should be one order of magnitude higher, energy range for X-rays would be extended from 10 keV to 50 keV).

CONCLUSION

A new panel of interests offered by the upgrade ELSA 2 facility is now proposed to users in terms, electron irradiation, γ-ray and x-ray productions. Short pulse beams (10ps, 14 MHz, 150 µs), high repetition rate (10Hz), high charged bunch (15 nC) delivered in 4 different experimental spots are the main features of this 18 Mev electron beam facility which can accommodate a wide range of user requirements.

ACKNWOLEDGMENTS

The author wishes to thank the ELSA team for helpful assistance and accomplishment in commissioning the ELSA 2 facility.

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