ELYSE – AN INTENSE ELECTRON LINAC FOR PULSED RADIOLYSIS RESEARCH

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Abstract

Recent years have seen an increasing interest in the use of intense, short pulse electron beams for pulsed radiolysis research. Laser driven photo-cathodes inserted in radio frequency guns are ideal candidates to provide 'pump' electron beams in pump-probe type experiments. These guns have been developed through accelerator R&D programmes in the field of high brightness sources for other applications (Linear Colliders, Free Electron Lasers). The Physical Chemistry Department at the Université de Paris-Sud has created a 'Centre de Cinetique Rapide' for experimental radiolysis with picosecond time resolution. At the heart of this new facility is a small ~ 9MeV electron accelerator, ELYSE, using RF gun technology. We will describe the construction and commissioning of ELYSE, the first machine of this type in Europe.

1 INTRODUCTION

ELYSE, the 'Centre de Cinetique Rapide' at Orsay is based around a femtosecond laser facility used for photolysis experiments and a picosecond electron accelerator used for radiolysis experiments. The combination of laser and electron beams will allow the physical chemistry community to perform pump-probe experiments with high temporal resolution. This paper will be concerned with the ELYSE accelerator, which is currently in the commissioning phase. Design and simulation work on ELYSE has been described elsewhere [1,2] and here we will concentrate on a description of the hardware and of the first beam tests. Table 1 summarizes the required beam parameters.

Table 1: ELYSE Beam Requirements

Beam energy	4 – 9	MeV
Pulse duration (FWHM)	< 5	ps
Charge per pulse	> 1	nC
Energy spread (RMS)	< 2.5%	
Normalized emittance (RMS)	< 60	mm-mrad

2 MACHINE DESCRIPTION

To obtain the beam characteristics shown in Table 1 we have chosen to employ an RF gun with a photo-cathode. The presence of the laser makes this a natural choice as precise synchronisation between the pump laser beam and the laser-triggered electron probe beam should be possible. The photo-cathode is triggered by a 267 nm laser pulse obtained from the frequency tripled 800 nm photolysis laser. The extractable photo-charge, Q, is given by,

$$Q(nC) = 8\ \lambda(\mu m)\ E_L\ (\mu J)\ \eta(\%)$$

Where λ is the laser wavelength, E_L the laser pulse energy and η is the quantum efficiency of the photo-cathode. Although the basic requirement is for 1 nC per pulse there is a strong interest in achieving 10 nC for some experiments. As the laser system is expected to deliver energies of the order of 10 μJ we require quantum efficiencies in the region of ~ 1%. Hence we have chosen to work with caesium-telluride photo-cathodes.

2.1 The RF Gun and Booster

As shown in Table 1, the energy of the ELYSE beam should be variable in the range of 4 to 9 MeV. The electron gun is a 1-1/2 cell, 3 GHz structure based essentially on the CLIC Test Facility (CTF) gun which has produced high bunch charges using Cs_2Te cathodes [3]. This gun will provide a beam of 4 MeV for an input power of 8.3 MW. The additional acceleration to reach 9 MeV is provided by a 4-cell SW booster cavity which is identical to that used on CTF. In order to allow the intense beam to propagate cleanly through the booster there is a water-cooled solenoid between the two RF structures.

2.2 The RF Distribution System

The RF power for the gun and booster is provided by a TH2130 klystron (20 MW, 4 μs) and a home built modulator. The RF network is designed to allow variable energy operation of the linac. The power from the klystron passes through a four-port ferrite circulator and is then divided into two branches by a 3 dB power splitter. The first branch is connected to the RF gun. The second branch is connected to the booster section and includes a variable attenuator, to adjust the energy gain from the booster, and an adjustable phase-shifter, to vary the booster phase with respect to the phase of the RF gun.

2.3 The Transport Line

After acceleration to the desired energy the beam can be transported to any one of three experimental areas

(EA). EA-1 is directly downstream of the accelerating section whereas EA-2 and EA-3 are at 30 and 60 degrees respectively to EA-1 (see figure 1). The beam is deviated to EA-2 or EA-3 with the use of rectangular dipole magnets (bend angle $\theta = 30°$, bend radius $\rho = 500$mm). Transverse focusing is assured by quadrupole triplets up and downstream of the dipole pair as well as a pair of quadrupoles between the two dipoles. The intensity and position of the beam is observed upstream of each EA by a Wall Current Monitor and a Faraday cup. Ceramic screens are used to indicate the transverse beam profile. At a later date Cerenkov radiation will be used to measure the bunch length using a streak camera [4]. An ajustable, and moveable, vertical slit placed a distance, L = 800 mm, downstream of the first dipole exit face gives some indication of the beam energy spread by measuring the horizontal beam profile. A system of five ion pumps distributed along the transport line maintains the required vacuum level for the machine.

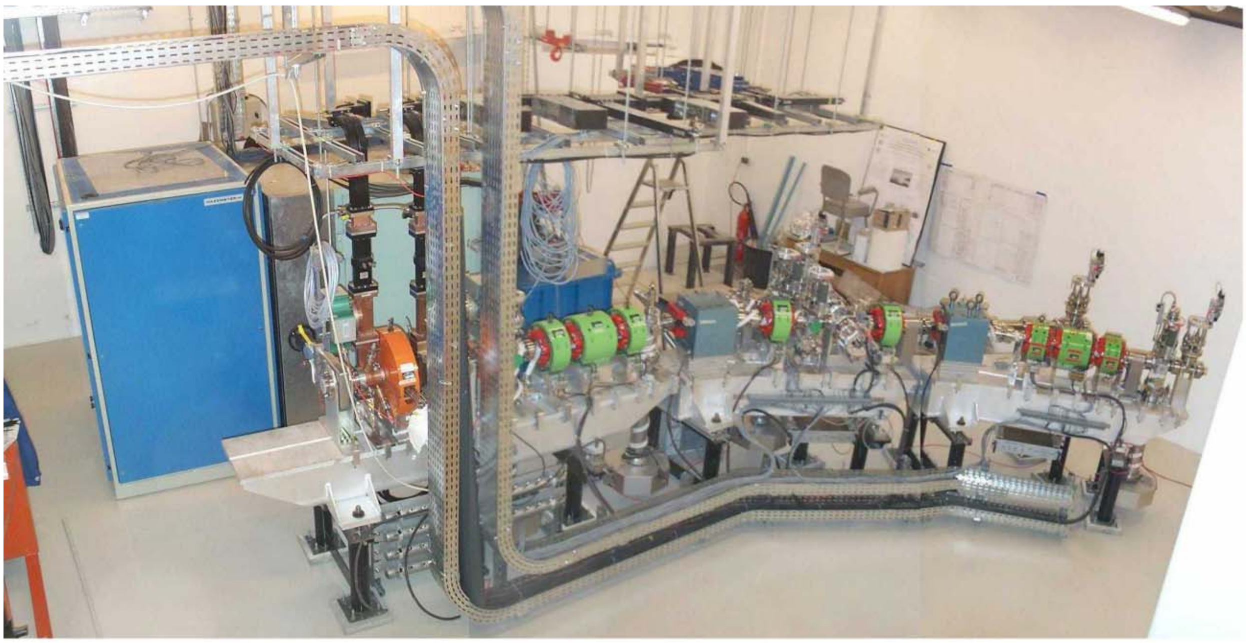

Figure 1. View of the ELYSE accelerator.

3 PRELIMINARY RESULTS

Following a period of conditioning of the RF distribution system, the RF gun and booster section (at 5 and then 10 Hz) a first attempt was made to produce a beam using a polished, but un-coated, copper cathode.

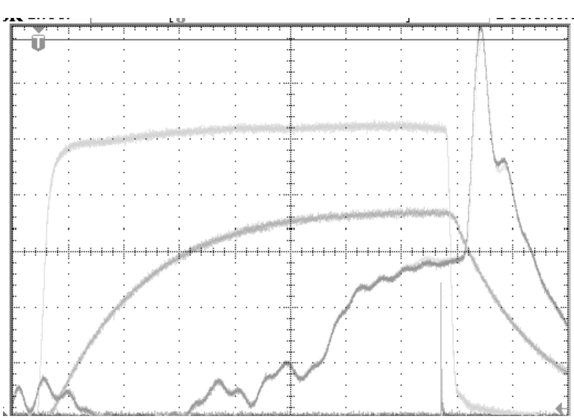

Fig. 2. Oscillogramme showing (left to right); The forward RF pulse to the gun, the RF filling of the gun, the electron pulse (dark current + photo current) and the laser pulse.

Figure 2 shows an oscillogramme with the electron current measured using the Faraday cup at EA-1. The figure clearly shows the photo-current signal superimposed on the dark current signal. The apparent width of the photo-current pulse is an artefact of the Faraday cup electronics (c.f. the laser pulse width). The incident RF power to the gun, P_{gun} is 5.2 MW (E_{acc} = 70 MV/m). During conditioning, dark current was detectable for gradients starting from 33 MV/m. As the quantum efficiency of the metallic cathode is poor the maximum charge extracted by photo-emission is ~ 100 pC (for a laser energy on the cathode of 20μJ).

After several days of operation at a repetition rate of 25 and then 50 Hz. we observed a dramatic increase in the level of the dark current signal and a strong increase in the temperature of the tuning plunger in the first (half) cell of the RF gun. In addition, the resonant frequency of the gun changed to a higher value. After modifying the position of the tuner its temperature during operation was reduced and the cavities resonant frequency restored to its normal value. However, this modification had no effect on the dark current which remains abnormally high. This increased dark current is still present even when the repetition rate is reduced again to 10 Hz. At the time of writing, the power in the gun is limited to 3.7 MW due to beam loading effects of the dark current. With this power level, and with a cathode which has received a coating of tellurium we have extracted charges of 270 pC per pulse. Although careful setting of the RF phases with respect to the laser phase remains to be done we observe about 70% of the photo-charge transmitted to EA-2 when the vertical slit width is set to 40 mm. Visual examination of the surface of the photo-cathode showed signs of surface damage (Fig 3). Despite changing the cathode we find that the dark current levels are still much stronger than those observed during our initial tests. For the moment, we have no explanation for this behaviour which is the subject of continuing investigations.

Figure 3. Copper cathode after removal from the RF gun. The cathode surface had been coated with tellurium prior to use.

We have performed rough measurements of the energy spread by varying the field in the first dipole and measuring the electron current behind the vertical slit, held at a fixed position (figure 4). These measurements were made with no power in the booster and $P_{gun} = 3.7$ MW. The energy spread $\Delta E/E \approx 12\%$ (FWHH). One would expect a horizontal beam width (neglecting the effects of finite emittance) of,

$$\Delta X \sim [\rho(1 - \cos\theta) + 2L\tan(\theta/2)]\,\Delta E/E = 62 \text{ mm},$$

A measurement of the beam profile for a fixed dipole setting while scanning the slits across the beam gives a width of 55 mm, in reasonable agreement with the above value.

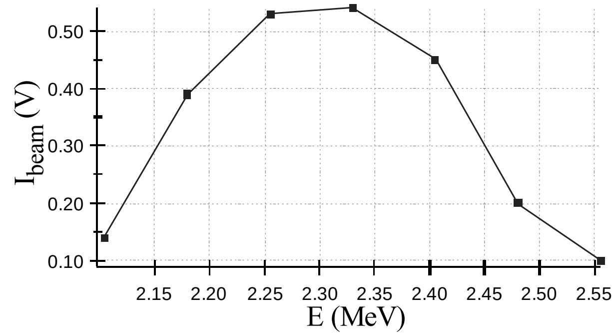

Figure 4. Energy spectra of the beam accelerated by the RF gun only. The slit width = 10 mm.

4 CONCLUSIONS

The ELYSE accelerator has produced its first beam, albeit with a metallic photo-cathode. Beam tests with a Cs_2Te cathode will take place in the near future. A sudden, and unexplained, increase in the dark current levels will be the focus of our studies in the immediate future.

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6 REFERENCES

[1] J.C. Bourdon et. al, "A High Charge Photoinjector for the Pulsed Radiolysis Facility - ELYSE", 19th International Linear Accelerator Conference (Chicago), pp , 1998.

[2] H. Monard et. al., "A Laser triggered Electron Source for Pulsed Radiolysis," Particle Accelerator Conference (New York), pp 2012-2014, 1999.

[3] R. Bossart et. al, "Modular Electron Gun Consisting of Two RF Sections and an Intermediate Focusing Solenoid", Nucl. Inst. And Methods, A 340, pp 157-163, 1994.

[4] M. Geitz et. Al., "Determination of the Longitudinal Phase Space Distribution Produced with the TTF Photo-Injector", Proceedings of the 21st Inernational Free Electron Laser Conference (Hamburg), pp II83-II84, 1999.