A LASER TRIGGERED ELECTRON SOURCE FOR PULSED RADIOLYSIS

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Abstract

We present the design of a photo-injector based accelerator for pulsed radiolysis applications. This machine is destined to meet the needs of the physical chemistry community at the Université de Paris XI. A 4 MeV electron pulse of a few picoseconds duration and with a charge in the range of 1 to 10 nC is produced from a Cs_2-Te photocathode. The photocathode is placed in the half cell of a 1-1/2 cell, 3 GHz RF gun, whose design is based on the gun used for the drive beam of the CERN CLIC Test facilty. A 4 cell ″booster″ cavity is then used to accelerate the beam to an energy of 9 MeV. The transport system consists of a quadrupole triplet downsteam of the booster, two rectangular, 30 degree bend, dipoles with a pair of quadrupoles between them and a second triplet downstream of the second dipole. Energy dependent path length effects in the two dipoles allow the possibilty of magnetic bunch compression depending on the phase-energy correlation of the bunch exiting the booster cavity. The beam envelope and the bunch length have been calculated through the transport line using TRACE-3d and PARMELA. These codes allow us to verify the required beam parameters at the experimental areas. We will discuss the adjustment of the optics, aimed at producing the minimum electron bunch length at the experimental targets.

1 INTRODUCTION

The project ELYSE aims to provide the physical chemistry community with a tool to study rapid chemical reaction dynamics. Chemical samples will be irradiated by a fast, high charge electron pulse and the resulting reactions will be analysed using a laser pulse synchronised with the electron beam. The necessity for both a laser and electron beam to perform such 'pump-probe' experiments suggests the use of a photoinjector for the electron beam, as the laser to be used as a probe can also be employed to produce the electron beam. The beam requirements necessary for ELYSE are given in table 1. Although the nominal charge per bunch is set to 1 nC one hopes to be able to produce more intense pulses (up to 10 nC) with similar pulse widths. In addition to these conditions there is a need to reduce the charge from the dark current arriving at the experimental samples to a level of < 1% of the charge of the primary beam. As the RF pulse width is of the order of 3 μs the dark current must not exceed a few microamperes.

Table 1: ELYSE beam specifications

Energy	4 - 9 MeV
Bunch charge	> 1 nC
Bunch duration	< 5 ps (FWHM)
Energy spread	< 2.5 % (RMS)
Normalised emittance	< 60 mm-mr (RMS)
Beam size on target	2 - 20 mm

2 THE ACCELERATOR

The layout of the accelerator, chosen to satisfy the ELYSE requirements, is shown in figure 1.

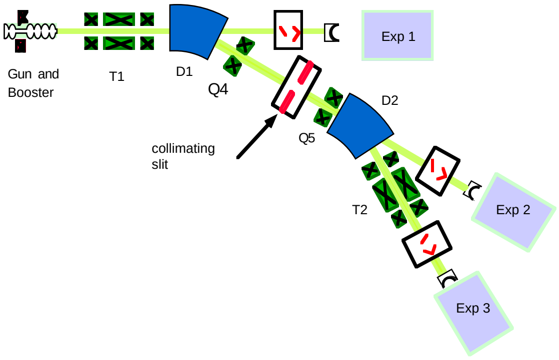

Figure 1. The accelerator layout.

It consists of a 1-1/2 cell RF gun, followed by a four cell ″booster″ cavity and a magnetic transport line to deliver the beam to one of three experimental areas (EA). The choice of the gun is based on the design used at CERN for the CLIC Test Facility [1]. The 1-1/2 cell gun will provide a beam of approximately 4 MeV while the booster cavity will allow further acceleration to 9 MeV. A solenoidal magnet is placed at the exit of the gun to focus the beam through the booster. The design of the transport line is chosen with two objectives in mind. The use of the two dipoles allows the dark current from the source to be filtered out before arriving at EA2 or EA3. If necessary, the collimating slit can further reduce the dark current but at the expense of losses in the primary beam. Secondly, the correlated phase-energy dependence of the

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beam leaving the booster can be exploited to provide temporal compression of the bunches due to energy dependent path length effects in the transport line [2]. This will help to compensate space-charge effects which will tend to lengthen the pulse duration, particularly on EA1.

3 SIMULATIONS

2.1 The electron gun

As stated above, the electron gun is based on the design used at the CTF. Nevertheless, we have made slight modifications to allow operation of the gun at lower cathode gradients (65 MV/m) with the aim of reducing the dark current while still allowing transport of the high charge through the booster. Optimisation of the gun was performed with SUPERFISH. The calculated field distribution was then used as input for PARMELA calculations of the beam envelope. The magnetic field of the solenoid was calculated with POISSON.

2.2 The transport line

The design and calculated settings of the transport line were made bearing in mind that the most important parameter, for the experimental targets is the bunch length. The layout of the line is rather classical. The beam exiting the booster encounters a first quadrupole triplet followed by two dipoles with a pair of quadrupoles between them and, finally, a second triplet. The machine has a point of symmetry centered between the pair of quadrupoles. This means that the dipoles, quadrupoles and triplets are identical as are the lengths of the corresponding drift spaces

The RMS beam parameters at the exit of the booster, calculated using PARMELA, were used to provide input Twiss parameters for TRACE-3d in each of the phase spaces (x,x'), (y,y') and (ϕ,E). TRACE-3d has the advantage of allowing quadrupole fitting procedures and permits one to quickly check on the transport. On the other hand, only the linear part of the space charge field is taken into account. For this reason, we used PARMELA to calculate the envelope through the entire machine with the quadrupole settings found using TRACE-3d. No major discrepancies are seen when comparing the transverse RMS beam enlevopes. However, the final bunch length calculated with PARMELA appears to be slightly longer than that calculated with TRACE-3d. The difference may be due to the inclusion of the non-linear space charge fields when using PARMELA.

Now let us discuss the transport setting from the exit of the booster up to EA3. The phase space co-ordinates at the exit of the transport line, x_i, are related to those at the entrance, x_{0j},by the transfer matrix R_{ij} using the equation,

$$x_i = \sum_{j=1}^{6} R_{ij} x_{0j} \qquad (i = 1,2,...,6),$$

where $x_i \equiv (x, x', y, y', \delta z, \delta p/p)$. First, we find the correct settings for the pair of quadrupoles (Q4 and Q5) in order to have the transport matrix elements $R_{51} = R_{52} = 0$. This setting makes the bunch compression independent of the geometric terms at the exit of the booster cavity. Moreover, it is also the correct setting for a first-order achromatic transport (neglecting space charge effects). The fields of the first triplet are then adjusted to give a reasonable value for the horizontal beam size between the two dipoles. Finally, the second triplet is set to deliver the required beam size, at EA3. It is then necessary to re-adjust Q4 and Q5 to maintain $R_{51} = R_{52} = 0$. If the gun and booster are adjusted to provide the required phase-energy correlation then bunch length compression occurs after the beam traverses the two dipoles.

2.3 The dipoles

The dipoles were designed with the 2D-codes POISSON and OPERA [3]. We have chosen to use rectangular, C-type magnets, with a 30° bend angle, and a bending radius of 500 mm. The main windings were calculated to produce a maximum magnetic field of 0.1 T. A secondary winding allows one to cancel remanent fields of the order of 20 G, in order to deliver the beam to experimental areas 1 & 2 when required.

2.4 Results

The initial conditions for the PARMELA calculation assume an RMS laser pulse, σ_τ = 1ps, truncated at ± 2.5 σ_τ. Figure 2 shows the phase-energy correlation at the exit of the booster for a 1 nC beam at 9 MeV. Even for the highest charge and lowest energies of interest, the beam exiting the booster meets the user requirements.

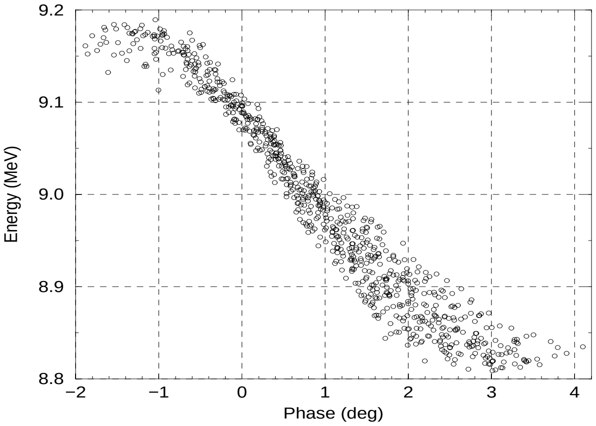

Figure 2. Energy-phase correlation at the booster exit.

The envelope of the same beam transported from the booster exit to EA3 is shown in figure 3. The calculated bunch compression in this case is 28% although we have shown that 50% can be achieved. At 9 MeV and 1 nC the desired pulse length is obtained (see Table 2, figure 3). At the lower energy of 4 MeV we still manage to transport 1 nC to EA3 but we see that the space charge effects lead to a longer pulse.

Table 2. Parameters at EA3 for 1 nC charge.

Energy	4 MeV	9 MeV
σ_τ	3.7 ps	0.8 ps
$\delta E/E$	3.6%	2.3%
RMS norm. emitt.	51 mm-mr	70 mm-mr

In contrast, we note that the charge of 10 nC cannot be transported without some loss in the second dipole. We continue to perform calculations to optimise the transmission at 10 nC.

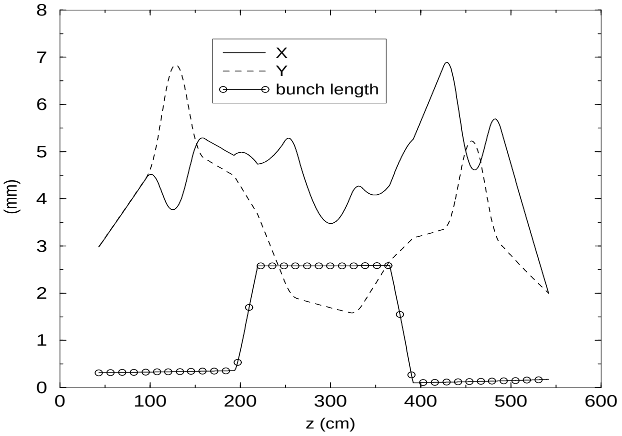

Fig. 3. The RMS values of the transverse and longitudinal dimensions of the beam through the transport line as calculated using TRACE-3d.

4 THE PREPARATION CHAMBER

As we aim to extract high charges (~ 10 nC) with a laser energy of ~ 50 µJ at 266 nm we choose to use a caesium-telluride photocathode. These cathodes, as well as having a high quantum efficiency (>1%), are now known to have a long lifetime, of the order one month [4] and exhibit low dark current [1]. However, the choice of such a cathode requires the use of a dedicated preparation chamber. We plan to install a simplified preparation chamber based on the design of a new chamber currently being installed at CERN for the CLIC Test Facilty probe beam [4].

5 PROJECT STATUS

In this paper we have mainly discussed the simulation work aimed at verifying that the desired beam performance can be obtained. In parallel with these calculations we have been making progress on the construction of the machine. Low level measurements have been performed on a prototype RF gun to fix the dimensions of the gun. We will use a booster structure which already exists. The entire RF network for feeding the gun and booster has been ordered from industry as has the klystron. The modulator will be built in-house. The quadrupoles and solenoid are under construction in industry and the dipoles are out to tender. Once delivered they will be tested using the facilities at LURE. The magnet power supplies will also be built by a group from the LURE laboratory. Position and intensity instrumentation is being developed at LAL. The control system has been contracted to industry and is well in progress. The vacuum system has been designed and many components are already on site with others ordered. The LAL drawing office is working on the design of many of the mechanical components (vacuum chambers, diagnostic ports, supports etc..). ELYSE will use an entirely commercial laser which has already been delivered.

The facility will be housed in an existing building which is currently being renovated. Installation and ‘first beam’ are foreseen for the summer of the year 2000.

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