CLIC STUDIES
THE DC TEST BENCH FOR LASER DRIVEN PHOTOEMISSIVE CATHODES

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Abstract

The DC test bench consists of a photocathode preparation chamber, a DC gun, a beam diagnostic line and an eximer dye laser.
Photocathodes produced are Cs_3Sb while Yttrium, Samarium and CsI cathodes are used as well.
The motion of the electrons in the gun and the following beam line has been computed under different space charge conditions.
We describe the test bench, present results with the different photocathodes, compare the computed optics with the beam measurements and report on the progress made with shortening the eximer laser pulses from nano- to picoseconds duration.

1. Introduction

The work started at CERN on linear colliders under the title of CERN Linear Collider (CLIC) covers a variety of subjects[1]. A CLIC Test Facility has been proposed (CTF) [2] in order to start experimental studies. The aim is to make available a source of very short (ps), very intense (10's of nC) electron bunches in order to test the various RF structures proposed for the main linac or for the drive linac. The generation of these bunches is in itself a development required for the main beam and for the drive beam of CLIC.

Such short, isolated bunches can only be produced from photoemissive cathodes illuminated by an intense laser pulse of a few picoseconds and placed in intense radiofrequency accelerating fields. This will be the aim of the main lab of the CLIC Test Facility. In order to start the fabrication and analysis of these photocathodes in a simplified and more easily accessible set up, it was decided to install a DC test lab in which the photocathodes could be evaporated, inserted in a DC gun and tested under high DC voltage conditions. The difficulty to develop picosecond instrumentation and the need to understand the properties of these photoemitted beams led to the installation of a short beam line after the gun for beam measurements and instrumentation tests. The assembly: evaporation chamber, DC gun and instrumentation beam line has been given the name of DC test bench.

2. Description of the DC Test Bench

The preparation chamber
We started with a simplified preparation chamber to achieve evaporation of cesium antimonide photocathodes. The evaporation was done at ambient temperature and only the thickness of evaporated layers was measured. The preparation chamber was equipped with: – 3 evaporators – a transfer arm for insertion and removal of the cathode in the DC gun – a thickness monitor – a removable shutter which shields the cathode from the evaporators – a vacuum pumping system giving a limit pressure of 5×10^{-9} Torr and a dynamic pressure of approx. 1×10^{-6} Torr during the evaporation process.

Recently the preparation chamber has been upgraded and the following features introduced : – quantum efficiency control during the evaporation process (the cathode is illuminated by the pulsed excimer laser and the photoemissive current is measured) – new pumping system, in ultra high vacuum range, giving a dynamic pressure of approx. 10^{-8} Torr during the evaporation process – controlled heating system to prepare multialkaline cathodes and cleaning system for metallic photocathodes are not yet installed.

The gun
The gun consists of two parallel plates separated by a gap of 1 cm and submitted to a difference of potential of about 80 kV (a DC field of 8 MV/m). The cathode hosts the photoemissive disk of 12 mm diameter, the anode has a hole of 16 mm diameter for the transmission of the electron and laser beams. The parallel plates geometry has been chosen to have the maximum field at the cathode (for a given gap voltage) and to achieve a maximum current density.

The beam line
The focusing is provided by air-cooled coils: three in the initial lay-out, increased to four to improve the beam current trasmission. For electrons with an energy of 80 keV, focal lengths of 10 cm can be achieved with about 2 Amps circulating in the coils. The first solenoid has an asymmetric shielding, with a small aperture (65 mm) on the cathode side, so as to minimize the magnetic field at the cathode.
The intensity and the longitudinal profile of the electron beam are measured by a Wall Current Monitor (WCM) at the starting of the beam line, a special luminescent screen with a high reflectivity in the UV range is used for first adjustments and image analysis and at the end of the beam line, charge measurements are made with a faraday cup.

Table I gives the parameters of the gun and solenoids, Figure 1 shows the lay-out of the bench

Table I
Gun and Solenoids Parameters

Gap	1	cm		
Gap voltage	80	kV		
Cathode radius	4	mm		
Sol. n.	B_{max}/I_{sol} (Gauss/A)	$\int\left[\frac{B}{B_{max}}\right]^2 dz$ (cm)	Nominal Optics z (mm)	 I_{sol} (A)
1	135.3	5.8	70	2.380
2	74.5	9.7	762	2.195
3	74.5	9.7	1454	2.195

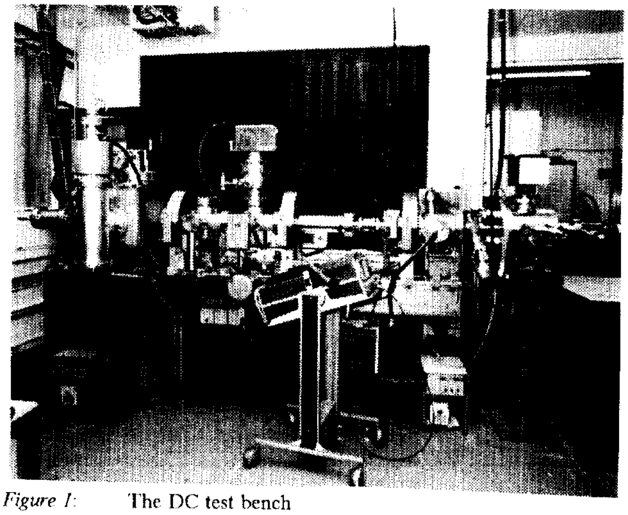


Figure 1: The DC test bench

3. Computation of the optics in the gun and in the beam line

The beam trajectories in the test line have been studied [3] with the help of three computer codes: the well known EGUN [4], written at SLAC, plus two home written programs, SOLOPT and PARAXIAL. EGUN simulates the dynamics in the gun, SOLOPT follows the electrons in the transport line after the accelerating gap using the results of EGUN; PARAXIAL reconstructs the dynamics on the whole line but in a rougher approximation inside the gun.

We shall rapidly pass through the approximations introduced in each of these two approaches, discuss their consistency and the agreement with the measurements done until now on the line.

For the computation of the beam optics a continuous beam is considered, composed of particles with zero kinetic energy at the cathode. The first approximation is justified by the observation that the transit time through the gap for 80 kV is about 120 ps: after a transient of about this time stationary conditions are installed and only the transverse dynamics have to be calculated. The length of the shortest bunches foreseen in the device is at the limit of validity of this hypothesis and some calculations with a more sophisticated code are required. PRIAM [5] integrates the equations of motion in time domain for pulses of finite length. Running this code it has been found that pulses with a charge of 0.3 nC and length 30 ps still follow in good approximation the dynamics of a continuous beam with 10 A current. The second approximation neglects the small thermal spread of velocities.

In Figure 2 the behavior of the beam, as calculated with EGUN, is shown for a current of 1 Amp. The boundary surfaces, the tracks of 23 macroparticles and the equipotential lines in the gap are plotted. The big beam divergence after the anode (about 130 mrad for the most external trajectory) is due mainly to the defocusing effect induced by the electrostatic lens created by the hole in the anode: for a flat cathode, in the approximation of an accelerating field going step-wise to zero at the anode surface, the focal length of this electrostatic lens is approximately four times the gap. The corresponding beam divergence at the anode exit has to be compensated by a solenoid situated as close as possible to the cathode; its longitudinal field is plotted Figure 2. The shielding on the cathode side of the solenoid decreases the magnetic field at the cathode improving the focusing effect of all the following solenoids.

It can be shown [6] that in the very ideal case of a point-like source followed by linear lenses, the motion is laminar everywhere except in the images of the source. With laminar motion we mean that for each value of the longitudinal coordinate z the divergence dr/dz is a univalued function of the particle displacement from the axis r. As a consequence the most external trajectory lies on the envelope and is submitted to a space charge radial force F_r

$$F_r = \frac{e}{2\pi\varepsilon_0\beta c}\,\frac{I}{r\gamma^2}$$

where I is the beam current, e is the electron charge, β and γ are the relativistic parameters. ε_0 and c have the usual meaning; both the electrostatic and the magnetic effects are taken into account. The EGUN outputs have confirmed that the emittance of the beam produced by the gun is small and the laminar approximation (quite well fulfilled in the gun) can be used for an estimation of the space charge force in the following beam line.

The optics in table I (solenoids positions and currents for 1 Amp beam current), chosen as the nominal one, has been calculated with good agreement between PARAXIAL and SOLOPT (about 1% in the optimum solenoid currents).

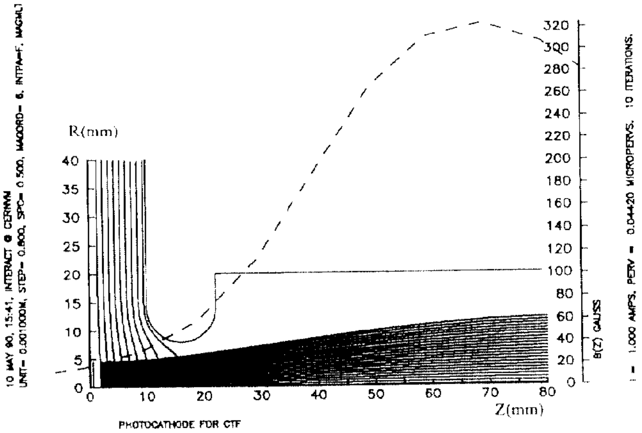


Figure 2: The cathode for a current of 1 Amp.

4. The Picola laser system

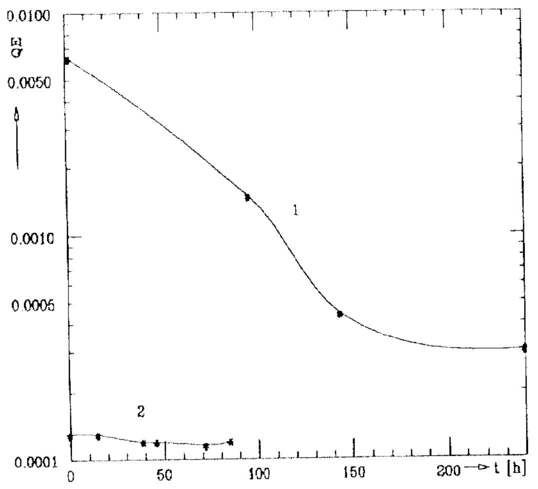
The laser system consists of a 150 mJ excimer laser, pulse duration 15 ns, which pumps several dye lasers.
Current work in the laser area concerns the verification of the pulse shortening technique known as tail quenching, which will provide the short pulses needed to investigate the photocathodes.
For this, the output of the pump laser is focussed by a cylindrical lens to a fine line in a dye cell. When the lasing threshold of the dye is exceeded, light is emitted along the axis in both directions. The pulses now have a length of 4 ns. The reverse pulse is reflected back into the dye cell at an angle slightly off the original axis. This causes the remaining energy in the dye to be used in a pulse aligned to this new axis.
The effect seen on the forward pulse is that the lasing action starts and is quickly quenched, giving a duration of 650 ps, which may then be amplified.

5. Preliminary results

Beam optics verification
Once the line had been assembled, an experiment was performed to verify the beam optics calculations, in particular in the gun region. At low current (5 mA), to avoid space charge blow up of the beam, we turned off all the solenoids but the first. The current of this solenoid had been tuned to compensate the defocusing of the electrostatic lens and to focalize the beam on the luminescent screen located 1784 mm away from the cathode. The long arm between solenoid and screen gives a good sensitivity to the measure of the solenoid current that generates the minimum spot size. A value of 1.7±.1 A was found, the uncertainty coming mainly from the evaluation of the focusing condition on the screen. The computations give a solenoid current of 1.73 A.

A second confirmation found is the value of the maximum current allowed by space charge. The current flowing from the cathode is limited by the charge of the already emitted particles. For a certain value of current this charge completely shields the accelerating voltage. For our geometry, a voltage of 70 kV and an emitting surface of 4 mm diameter (the laser spot size), the maximum current predicted by EGUN to reach the Wall Current Monitor is 11 A, in good agreement with the experimental results.

A new optics has then been calculated to fully transmit the beam to the faraday cup. A fourth solenoid has been introduced and the position of the others has slightly changed. This new lay-out is implemented and tested at low beam current.

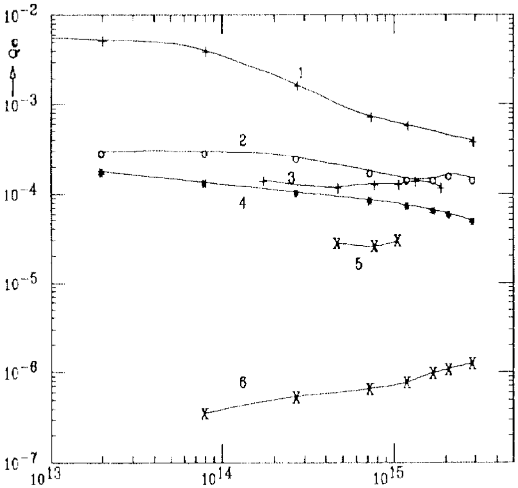


Laser beam : λ = 266 nm ; Φ = 4±1 mm ; W ≈ 0.45 μJ
: Pulse width 10 ns FWHM
Cathode : stainless substrate ; Φ = 12 mm
Curve 1 : 68 nm of Cs deposited above 6 nm of Sb
Curve 2 : 6 nm of Sb deposited above 68 nm of Cs

Figure 3: QE versus time at low current

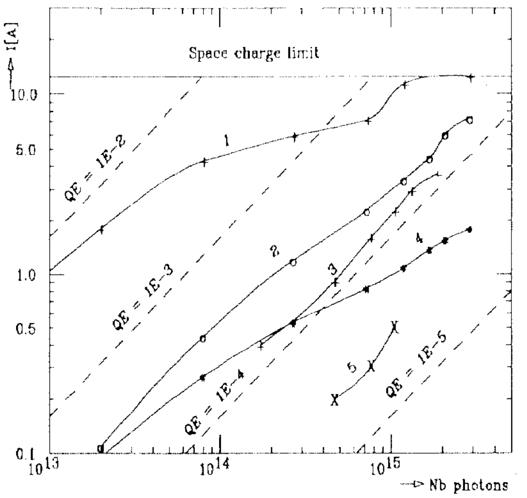
First photocathodes

After some tests with a hydrogen lamp we used a Nd:YAG laser with a frequency quadrupler for the light source. The cesium antimonide cathode was prepared [7] according to the stoichiometric ratio of Cs_3Sb with 6nm of antimony deposited on the stainless substrate at a mean rate of 0.6nm/s and with 68nm of cesium deposited on the antimony at the mean rate of 0.24nm/s. The electrons created were accelerated to 70 keV and measured with the WCM. Figure 3 curve 1 gives the life time of this photocathode at low current (from 1 mA to 60 mA).



Laser beam : λ = 266 nm ; $W(mJ) \approx 0.75 \times 10^{-15} \times Nb_{photons}$
: Φ = 4±1 mm; Pulse width 10 ns FWHM
Cathode : stainless substrate ; Φ = 12 mm
Curve 1 : 68 nm of Cs above 6 nm of Sb after 2 h
Curve 2 : 68 nm of Cs above 6 nm of Sb after 250 h
Curve 3 : 6 nm of Sb above 68 nm of Cs
Curve 4 : CsI cathode , thickness = 350 nm
Curve 5 : Yttrium Φ = 8.5 mm, thickness = 0.25 mm
Curve 6 : Stainless steel

Figure 4: QE versus number of photons



Laser beam : λ = 266 nm ; $W(mJ) \approx 0.75 \times 10^{-15} \times Nb_{photons}$
: Φ = 4±1 mm; Pulse width 10 ns FWHM
Cathode : stainless substrate ; Φ = 12 mm
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Curve 4 : CsI cathode , thickness = 350 nm
Curve 5 : Yttrium Φ = 8.5 mm, thickness = 0.25 mm

Figure 5: peak current versus number of photons

The maximum current obtained was limited to 12 amps by the perveance of the gun for a laser beam diameter of about 4 mm. The second photocathode was prepared in the same manner but by depositing at first Sb. The quantum efficiency – defined as the ratio of the number of electrons measured at the exit of the gun over the number of incident photons on the cathode – remains constant in time, but is lower than the minimum quantum efficiency obtained with the first cathode (Figure 3 curve 2). The accuracy of measurement of the quantum efficiency is not better than ±30%.

We also have tried some other photoemissive materials like cesium iodine (350 nm of CsI according to [8]) and metals (Yttrium and Samarium). These cathodes were prepared outside the preparation chamber and consequently no optimum surface conditions were achived. Figure 4 and Figure 5 give for some cathodes, respectively, the quantum efficiency and the peak current versus the number of photons.

6. Future plans

The first priority is to improve the accuracy of the measurements and develop new beam monitors for the range of 10 to 100 ps pulse width.

With the modified preparation chamber a number of classical photocathodes will be made and tested in the DC gun. By alternating deposition of Sb and Cs at 150 °C and by monitoring the photoemission during the process we expect to make some photoemissive surfaces with a high quantum efficiency. We then will try to build cathodes with life times longer then the Cs_3Sb ones. Profiting from experiences gained elsewhere we shall make multialkalides; K_2CsSb and others. The quality of the photocathodes depends largely on the vacuum pressure obtained in the evaporation chamber during the process and in the DC gun during the testing.We expect to have a pressure of 10^{-9} Torr at least. Another evaporation chamber will be constructed to achieve lower pressures and to provide better evaporation conditions.

The RF gun under construction will be ready for testing this summer. Awaiting the system which will permit to transfer under vacuum a photoemissive cathode made in the preparation chamber into the RF gun, we will rely on metallic photocathodes such as Yttrium and Samarium.

7. Acknowledgements

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