EXPERIMENTAL RESULTS ON THE PHIL PHOTO-INJECTOR TEST STAND AT LAL

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Abstract

The PHIL accelerator is in operation since November 2009. Its main goals are the R&D on photo-injectors and to provide electron beam to users. We report on the experimental characterization of the electron beam produced by a 3 GHz 2,5 cells RadioFrequency (RF) gun and operation with a Magnesium photo-cathode.

INTRODUCTION

The PHIL beamline [1,2] is rather simple : the photo-injector at 3 GHz called AlphaX [3] equipped with a couple of solenoids, a pair of steerers, a third solenoid to transport and focus the electron beam and a dipole to analyse the beam energy. The main diagnostics are Integrated Current Transformers (ICT) from the Bergoz Company to measure the charge and YAG screens coupled with a CCD camera to measure the transverse profile of the beam. Main parameters of the electron beam are summarized in table 1.

Table 1: PHIL Electron Beam Parameters, with Cu Photo-Cathode Except Few Runs with Mg*.

Energy (MeV)	< 5
Charge (nC), single pulse	0.01-0.4; 1*
Energy spread (%)	< 1
Emittance (πmmmrad)	< 5
Repetition rate (Hz)	5

COMMISSIONING

The RF gun has been commissioned several times rather easily. Generally it took a day to reach 5.5 MW with a RF pulse duration of 2.5 µs which is equivalent to an accelerating field of 70 MV/m. The RF commissioning has been repeated several times due to some changes of photo-cathode; we tried raw copper, copper polished with diamond paper and magnesium photo-cathodes. The commissioning took place smoothly thanks to the elliptical shape of the irises between the cells. It leads to a ratio of the surface electrical to the accelerating field close to one, thus reducing breakdown hazards.

Dark Current

The dark current or charge has been measured as a function of the accelerating field for raw copper and hand polished photo-cathodes. It was not possible to compare with the optically polished photo-cathode because of a breakdown in the RF circulator which did not allow us to increase the electrical field above 40 MV/m.

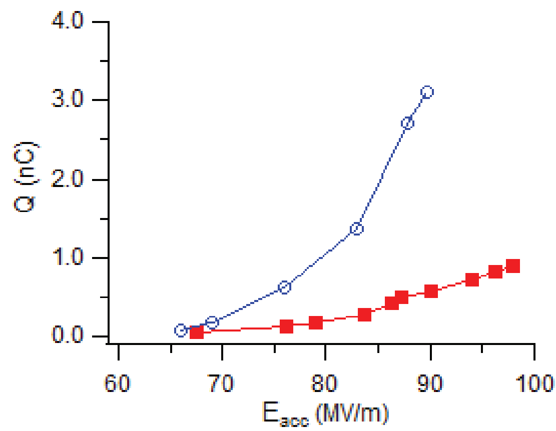

Figure 1: dark charge produced by field emission in the gun for raw copper (round points) and hand polished copper (square points) photo-cathodes.

The reduction of dark current due to the use of a polished photo-cathode is spectacular. At 90 MV/m, the dark charge with polished photo-cathode is 5.5 times lower than in the raw copper case. However, the analysis of these results according to the Fowler-Norhdeim formula [4] showed that the field amplification factor, β, has the same order of magnitude, around 100. The lower charge with the polished copper comes actually from a reduction of the emission area.

BEAM PERFORMANCES

To compare performances of different photo-injectors and also for user experiment, it is important to characterize the electron beam as a function of parameters as the relative phase between the RF and the laser, the accelerating gradient, the energy and spot size of the laser.

Dephasing Curve

The best performances of the electron beam are obtained when the electron beam is accelerated near the crest of the RF wave. However there is a range around the optimum phase on which the gun can be operated. Measurements of the beam charge as a function of the relative phase between the laser and the RF is shown in figure 2.

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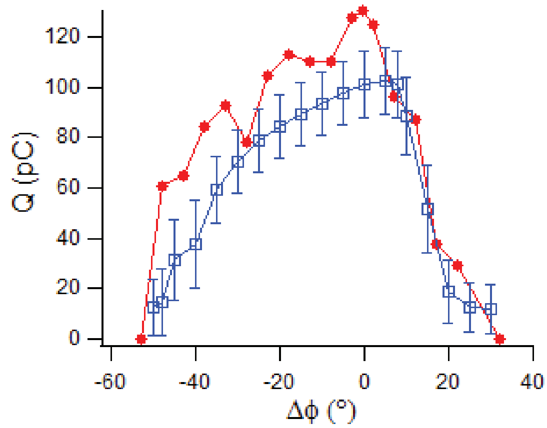

Figure 2: beam charge as a function of the relative phase between the RF and the laser for 56 MV/m, blue curve with squares and 92 MV/m, red curve with circles.

Behaviour is similar as observed in other experiments [5]. The width of the dephasing curve increases versus the accelerating gradient. Below the phase corresponding to the maximum charge, there is a slow increase due to the Schottky effect related to the increase of the accelerating gradient. On the right side of the curves, the slope is very abrupt; in less than 10° the charge can decrease by 50 %. It means that the beam performances are very sensitive to the phase. Besides there is evidence of a slow drift of the phase which is being investigated.

Transverse Dimensions and Emittance

Transverse dimensions of the electron beam are measured through the fluorescence light emitted by the beam into YAG:Ce screen. This light is then transported by a metallic mirror, an achromatic lens to a CCD camera. Four monitors are installed, the first at around 2 meters away from the photo-cathode, the second is placed just after a focusing coil in the middle of the beamline (3.5 m from the photo-cathode), the third is at the end of the straight line and the last on the deviated line after the dipole for the beam energy measurement.

Example of typical measurements is shown in figure 3.

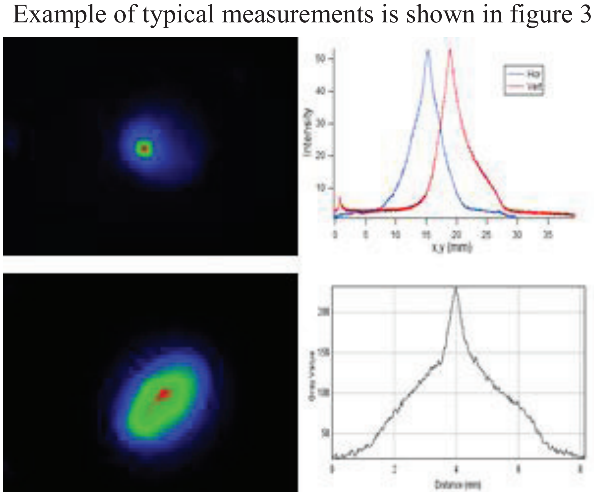

Figure 3: YAG screen images; top, 1st screen with the 1st focusing coil at 90 A; down, 2nd screen with 99 A and the 2nd focusing coil at 29 A; Q = 180 pC, E_{acc} = 63 MV/m.

The difference between both images is clear: on the first screen, the beam appears mostly round although with a vertical width 12 % larger than the horizontal one. On the second screen, it is elliptical tilted at roughly 45°; the width along the big axis is 51 % larger than on the other axis. The profile on the first screen is probably due to the laser which has a vertical width also 5 % larger than the horizontal one. However it is not enough to explain the huge ellipticity of the electron beam measured on the second screen. It looks like the action of a quadrupole or it would mean that the vertical emittance of the beam is 50 % larger than in the other direction. Both hypothesis do not seem compatible with our set-up, this problem is still under investigation. In addition there are also some problems of halo and parasitic images that we are striving to understand.

In spite of these problems, we used a solenoid scan to measure the emittance. A direct measurement with a mask made of vertical and horizontal slits is foreseen in 2013, technical drawings are under way. The principle of the measurement with the solenoid is similar to the one with the quadrupole. One measures the beam transverse dimensions as a function of the magnetic force and, knowing the coil transfer matrix, it is possible to deduce the beam matrix at the entrance of the coil. Such measurement is shown in figure 4.

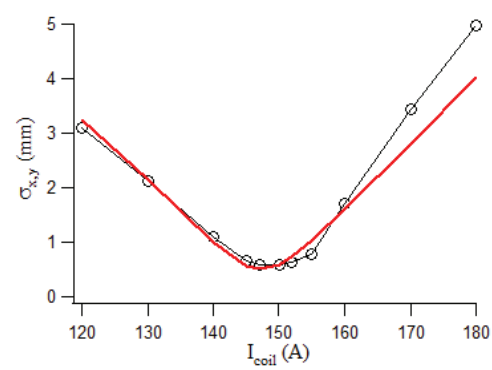

Figure 4: rms beam size, black curve with round points; least square fit restricted to [130, 160] A, red curve; Q = 150 pC, E_{acc} = 80 MV/m.

Some reasonable assumptions have been made to simplify the analysis: the beam is round and no coupling terms between the X and Y directions in the input beam matrix. So, only 3 parameters of the beam matrix must be found: σ_{11}, σ_{12} and σ_{22}. The fit was restricted to the current range [130 A; 160 A] because on the whole range of current it converged to a solution giving an imaginary emittance. So, the result of the fit is a normalized emittance of 4.6 πmmmrad. With the parameters of the experiment, PARMELA simulation gives an emittance of 2.6 πmmmrad at the entrance of the coil. The discrepancy between the simulation and the experiment can have multiple origins: problems with the images, magnetic errors, RF phase error and the fact that this method based on the transport matrix formalism neglects the space charge force. In the simulation, the emittance increases by

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30 %, between the position of the YAG screen and entrance of the solenoid, due to the space charge.

Energy spread

The energy spectrum of the electron beam is measured thanks to a dipole recycled from the TTF accelerator. It is a 60° bend with 70 cm of curvature radius. The YAG screen used to measure the beam is close to the focal plane of the dipole, at 13 cm, which means there is a small contribution of the transverse dimension on the measurement. We performed a measurement of the energy spread as a function of the RF phase, shown in figure 5.

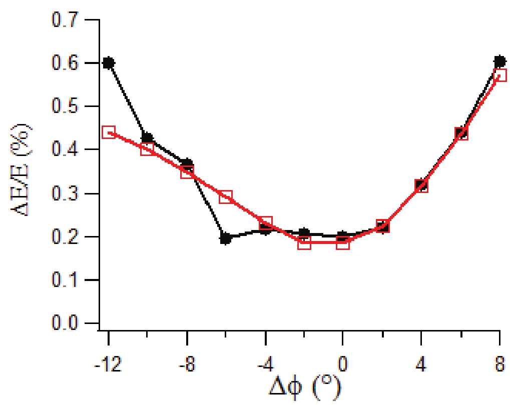

Figure 5: rms energy spread as a function of the RF phase with Q = 100 pC and E_{acc} = 54 MV/m; measurements, black curve with rounds; PARMELA simulations, red curve with squares.

The minimum energy spread is roughly 0.2 %. PARMELA simulations have been performed with the experimental parameters. The agreement with the measurements is quite satisfying. It means also that the contribution of the emittance in the measurement is negligible as we had assumed.

MAGNESIUM PHOTO-CATHODE

Several experiments have been performed elsewhere with magnesium (Mg) photo-cathode to produce higher charge [6]. The advantage of such materials is the relative easiness and low cost to carry out compared to cesium telluride for instance. We used a disk of pure Mg of 10 mm diameter and 2 mm thickness and press fitted in the centre of the copper end plate of the RF gun without baking or cleaning. The RF commissioning was 3 times longer than with the simple copper plate. The first beam with this photo-cathode produced very low charge, 80 pC at the maximum but it was expected. To have access to the good properties of pure Mg, one has to remove the oxide layer on the surface. The simplest way to do it is to focus the laser down to 0.1 mm; to scan the photo-cathode in presence of a RF field of 50 MV/m and to make explode the top oxide layer. After having performed this procedure, we measured the charge as a function of the laser energy, see figure 6.

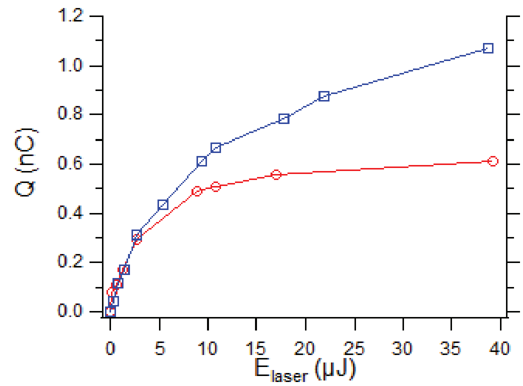

Figure 6: beam charge measured with an ICT as a function of the laser energy deposited on the Mg photo-cathode for 2 accelerating gradients; 45 MV/m, red curve with circles; 62 MV/m, blue curve with squares.

The laser cleaning led to a dramatic increase of the extracted charge, up to 1.1 nC with an accelerating field of 62 MV/m while it was only 80 pC before. Actually, we are limited by the space charge force which prevents the electrons to go out. As one can see, increasing the accelerating gradient allows one to extract more charge. The linear part of the curves, below 5 μJ, means a yield of 0.11 nC/μJ. If we could operate the gun at 90 MV/m, we could produce 4.4 nC with the maximum laser energy.

CONCLUSION

Experimental characterisation of the alphaX photo-injector has been performed. Charge, emittance and energy spread have been measured and are in good agreement with the simulations. Obtaining of high charge with magnesium photo-cathode has been demonstrated. Next step will be to operate at high gradient routinely in order to improve beam quality and higher charge. We plan also to test other RF guns and to perform user experiments.

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