PERFORMANCE OF THE PHIN HIGH CHARGE PHOTO INJECTOR*

M. Petrarca#, E. Chevallay, S. Doebert, A. Dabrowski, M. Divall, V. Fedosseev, N. Lebas, T. Lefevre, R. Losito, CERN, Geneva, Switzerland
D. Egger, O. Mete, CERN, Geneva and EPFL, Lausanne, Switzerland

Abstract

The high charge PHIN photo injector is studied at CERN as an electron source for the CLIC Test Facility (CTF3) drive beam as an alternative to the present thermionic gun. The objective of PHIN is to demonstrate the feasibility of a laser-based electron source for CLIC. The photo injector operates with a 2.5 cell, 3 GHz RF gun using a Cs_2Te photocathode illuminated by UV laser pulses generated by amplifying and frequency quadrupling the signal from a Nd:YLF oscillator running at 1.5GHz. The challenge is to generate a beam structure of 1908 micro bunches with 2.33nC per micro bunch at 1.5GHz leading to a high integrated train charge of 4446nC and nominal beam energy of 5.5MeV with current stability below 1%. In this paper we report and discuss the time resolved transverse and longitudinal beam parameters measurements. The performance of the photo cathodes made at CERN with a peak quantum efficiency of 18 % is shown as well. Laser pointing and amplitude stability results are discussed taking into account correlation between laser and electron beam.

INTRODUCTION

The third CLIC Test Facility (CTF3) has to demonstrate all the key issues of the CLIC two-beam acceleration scheme [1]. The drive beam is currently produced by a thermionic gun followed by a sub-harmonic bunching system required to generate the required time structure for CTF3. A photo-injector is an attractive alternative [2] providing a lower emittance beam and more flexibility on timing structure. In addition, the satellite pulses produced by the sub-harmonic bunching scheme could be suppressed completely. Therefore the PHIN R&D activity is devoted to demonstrate the feasibility of a high charge injector with high current stability.

The development of this photo injector was funded by the Joint Research Activity "PHIN" of CARE (Coordinated Accelerator Research in Europe) and it has been built in collaboration between LAL, STFC and CERN. LAL was responsible for the design and construction of the RF gun [3]. The laser was designed and built by STFC and CERN [4-5]. CERN as the host of the installation is taking care as well of the overall project coordination and the commissioning and operation of the facility. Contributions came also from LNF/INFN.

PHOTO INJECTOR

The PHIN photo-injector [6-7], see Fig 1, was designed to deliver a train of 1908 electron bunches at 1.5 GHz bunch repetition rate. The laser was designed for a train repetition rate of up to 50Hz. Details of the rf-gun design optimized for high charge operation and excellent vacuum can be found in [3, 6, 7]

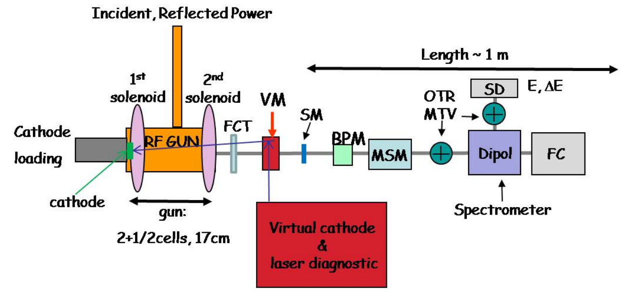

Figure 1. Photo injector layout: symbols explanation is given in the text.

The required and the achieved photo injector parameters are reported in Table 1. All the main requirements have been satisfied. The achieved stability will be discussed in laser section.

Table 1: PHIN Parameters

	Project	Achieved
Charge per bunch (nC)	2.33	4
Train length (ns)	1273	1300
Total Charge (nC)	4446	3600
Normalized emittance (π-mm-mrad)	< 25	8
Energy spread (rms)	<1%	0.7%
Energy (MeV)	5.5	5.5
Charge stability (rms)	<0.1 %	(1-2)%
UV laser pulses energy (nJ)	370	400
Cs2Te cathode QE	3%	18% peak

Two solenoids have been placed around the gun: a solenoid for the emittance compensation process and a backing coil solenoid to cancel out the magnetic field on the cathode. A fast current transformer (FCT) has been installed directly after the gun to monitor the extracted charge with sufficient bandwidth to resolve the current profile along the train. At the end of the line a Faraday cup (FC) is installed to have a second independent charge measurement and to optimize beam transport. A mirror (VM) is used in the vacuum line to redirect the UV laser beam onto the cathode. Steering magnet (SM) and beam positioning monitor (BPM) are used to optimize the beam transport. The system consisting of the multi-slits mask (MSM) and the Optical Transition Radiation (OTR) screen [6, 7, 8] is installed for the emittance measurements of the low energy, space charge dominated beam. The energy spread measurements in the produced electron beam with time resolution along the 1.3 μs train are done using an OTR screen equipped with a gated camera in the dispersive region and a segmented beam dump at the end of the spectrometer line.

LASER

The front end of the laser system consists of a commercial (High Q Laser Innovation) Nd:YLF oscillator, which produces a continuous train of pulses at 1.5 GHz repetition rate synchronized to the RF of the machine to <1ps accuracy. The pulses have a central wavelength of $\lambda\sim$1047 nm an energy of 0.2nJ (300mW average power) and a FWHM of $\tau\sim$8 ps. The train of pulses is amplified first in a cw amplification stage up to 10W average power (6.6 nJ/pulse). This is followed by two powerful pulsed amplifiers AMP1 and AMP2, designed at STFC and re-constructed at CERN, see [4-5] and refs. therein, which work in steady-state to achieve the high stability required and bring the power level up to 8.3kW pulse train mean power (5.5μJ/pulse). The duration of amplification bursts is 400 μs and the burst repetition rate is 1-5 Hz. Flat 1.3 μs trains of amplified pulses are sliced out of the final burst section by means of a fast Pockels cell. The energy of the sliced train of amplified laser pulses has an excellent 0.23 % rms stability in the laser room. Since the Cs_2Te photocathode requires UV pulses a second and fourth harmonic generation stages have been implemented in collaboration with CEA Saclay (France) and IAP Nizhny Novgorod (Russia). A non-linear KTP crystal of type II is used to generate the second harmonic with 47 % conversion efficiency. The forth harmonics are generated using either an ADP crystal in the noncritical phase-matching mode (conversion efficiency 35 %), or a KDP crystal of Type I phase matching (18% efficiency) for better beam profile. With both crystals the nominal 370 nJ/pulse is delivered to the cathode. The UV beam generated in the laser room is optically relaying through an ~11 m long transport line to the cathode via a diagnostics table installed in the machine area close to the photo-cathode chamber. A remotely controlled flipping mirror allows a direct energy measurement of the full beam. An online measurement of the reflected beam from the viewport is also available. By a virtual cathode (VC) camera we acquire beam profile and make position measurements at the cathode plain. Satisfactory correlation between the movements of the electron beam with the laser beam has been observed. A factor of three better pointing stability in the laser room, than on the VC has been observed. Improvement could be expected from either installing a window between the laser room and the machine area to avoid air flow, or from fully enclosing the beam. The macro-pulse amplitude stability measurement over the ~1.3μs train was obtained by energy measurement and by measuring the integration of the window of interest from the VC camera, which show good agreement. Simultaneously the charge stability was also measured, using beam position monitors and taking an average value over 17 electron bunches at the first part of the train. A current stability within (1-2)% rms has been measured, which corresponds well to the laser stability.

PHOTOCATHODE

CERN hosts a photoemission laboratory which has been equipped to produce high quality Cs_2Te photocathode by co-evaporation process. During the cathode production, the stochiometric ratio of the deposed compound (Cs, Te) as well as the quantum efficiency (QE) can be monitored in order to stop the process when the cathode has reached an optimum performance with peak QE value. The laboratory is also equipped with an ultra high vacuum (UHV) transport carrier which allows the transfer and installation of the produced cathode into the rf gun preserving the produced high QE. For the PHIN experiment discussed in the following sections a cathode with 18% peak QE have been produced. The integrated extracted charge was measured for different train lengths and three different laser pulse energies see Fig.2. The

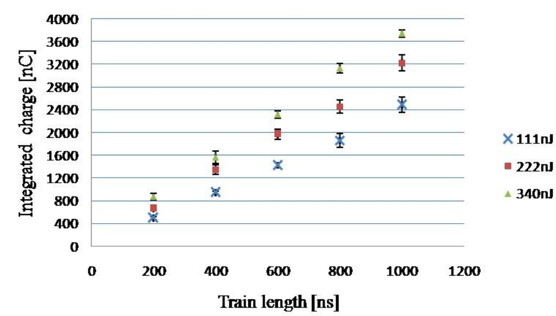

Figure 2: Integrated charge as function of train lengths for three different laser pulse energies: 111, 222 and 340 nJ. Laser transverse size σ~0.3mm.

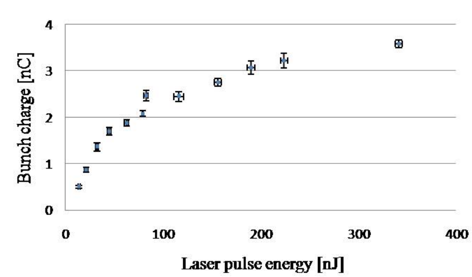

Figure 3: Electron bunch charge as a function of the laser pulse energy for 200ns train of laser pulses. Laser transverse size: σ ~0.3mm.

linearity of the result suggests that the cathode response is not affected by the high integrated charge or high integrated laser energy. However, the slope coefficient does not change linearly with respect to the laser pulse energy. This can be explained by the saturation behavior of the current extraction process yielding to a lower effective QE for higher laser pulse energies. To illustrate this effect, the charge per bunch was measured at a fix train length (200ns) as a function of the laser pulse energy, see Fig 3. In the measurements reported in Figs. 2, 3 the transverse laser beam size was σ~0.3mm.

BEAM DYNAMIC MEASUREMENTS

In this section we report studies concerning the stability of the beam parameters along the pulse train. For the beam dynamics measurements described below, the beam was injected about 30 deg later with respect to the phase of RF field extracting the maximum charge. This phase has been determined through simulations to achieve the best compromise between emittance, energy spread and bunch length. In Fig 4, the beam sizes and the emittance measurements [8] in different slices along the bunch train are shown. The data was obtained by taking beam images

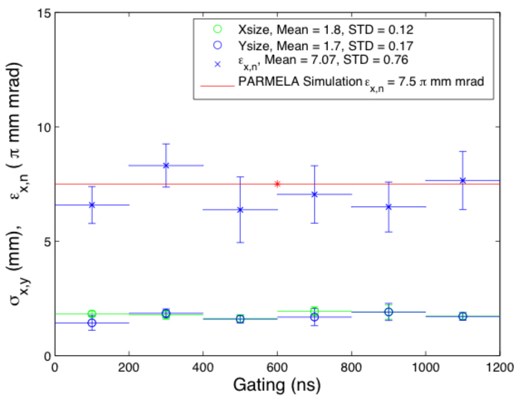

Figure 4: Beam sizes and the emittance along the pulse.

produced on the OTR screen with a gated intensified camera. The gate was set to 200 ns and its timing was delayed by 200 ns for each data point and it is represented by the horizontal bars. Each data point represents the average over 10 subsequent measurements in the same gating period and the vertical error bars take into account the statistical fluctuations. An emittance fluctuation of 1.13 mm mrad along the pulse train has been calculated as an average over the statistical deviation for each gated position. This variation is more likely to be due to the measurement error, than due to a real emittance variation along the train. The train has an energy of 5 MeV and the focusing solenoid current is 202 A.

The beam energy and energy spread have been measured in a similar way using the screen in the dispersive section after the spectrometer magnet. In Fig. 5. the results of the

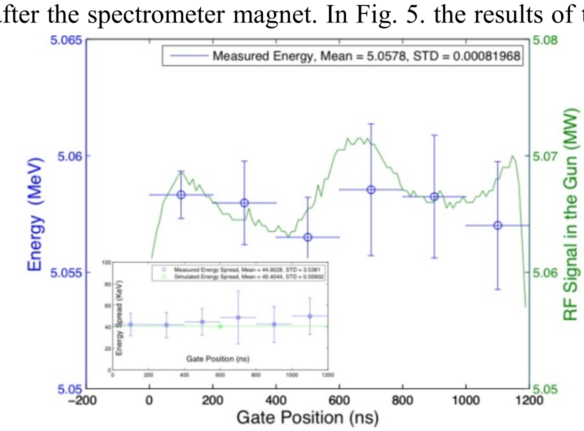

Figure 5: Energy and the energy spread along the pulse.

energy and the energy spread measurement along the pulse train are shown with the relative standard deviation, determined by the shot to shot fluctuations. The systematic energy variations along the pulse fit well to the changes of the rf power along the pulse due to non-optimized flattop of the high-voltage pulse frorn the RF modulator. This example shows nicely the sensitivity of the time resolved measurements to such kind of perturbations.

CONCLUSION AND PERSPECTIVE

The PHIN photo-injector demonstrated most of the main design parameters. Nominal bunch charge at nominal train length was reached as well as the required energy and energy spread with satisfactory stability along the train. To improve the current fluctuations rising from the laser, a feedback stabilization system will be implemented during 2011 on the laser, aiming to reach the target 0.1% rms amplitude stability at the cathode. The laser pointing stability can be improved by better isolating the transport path to avoid air flows due to temperature differences.

To create the right time structure for beam combination to 12GHz for CLIC a phase coding system, based on fiber electro-optic modulators, will be installed on the laser by the end of the year. The charge extraction process form the cathode shows a saturation effect most likely due to a space charge limitation. It is planned to study this effect in more detail at different laser spot sizes. Cathode behaviour investigation as a function of laser energy as well as the cathode response to long high charge trains is important for the future CLIC Photo-injector design.

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