RECENT DEVELOPMENTS AT THE HIGH-CHARGE PHIN PHOTOINJECTOR AND THE CERN PHOTOEMISSION LABORATORY

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Abstract

The high-charge PHIN photoinjector has originally been developed to study the feasibility of a photoinjector option for the drive beam of the CLIC Test Facility 3 (CTF3) at CERN and is now being used to investigate the feasibility of a drive beam photoinjector for CLIC. In this paper recent R&D efforts to improve the parameters of the existing system towards CLIC requirements will be discussed. This includes studies of a feedback loop for intensity stabilization, the upgrade of the PHIN vacuum system and the planned upgrade of the driving laser system. For photocathode production and R&D a dedicated photoemission laboratory is available at CERN. To increase the production rate of photocathodes and the availability of the photoemission lab for other studies, an upgrade of the photocathode preparation system with a load-lock system is under study and will also be presented.

INTRODUCTION

The Compact Linear Collider (CLIC) is a future e^+e^- collider, which is currently under study by a worldwide collaboration led by CERN [1]. It features a unique two-beam acceleration scheme, which requires a drive beam accelerator with high peak and average currents. In the baseline design, this beam is foreseen to be produced by a thermionic electron gun and a sub-harmonic bunching system [2]. However, this scheme results in the generation of parasitic satellite pulses, which cause beam losses and radiation issues. To overcome these limitations a photoinjector option is under study and the photoinjector PHIN [3] was constructed at an off-line test stand at the CLIC Test Facility 3 (CTF3) at CERN to investigate its feasibility as a CTF3 drive beam source.

It has been demonstrated that PHIN is capable to produce practically satellite-free beams with the required time structure [4]. The CTF3 and much more the CLIC drive beam parameters are challenging for a photoinjector (Table 1). Especially the combination of 140 µs long trains, 8.4 nC bunch charge, 0.5 GHz bunch repetition rate and 50 Hz macro-pulse repetition rate for CLIC is beyond the parameters of any existing photoinjector. This unique parameter set imposes several challenges on the CLIC photoinjector design, which are addressed at PHIN during the current study. Since PHIN was not designed for CLIC parameters but for the CTF3 beam, efforts are on-going to improve PHIN towards CLIC requirements, which will be discussed in this paper.

The photocathodes used at PHIN are produced at the CERN photoemission lab. To increase the number of produced photocathodes, an upgrade of the photocathode preparation system with a load-lock system is under study and will be discussed in the second part of this paper.

Table 1: Requirements for CTF3 (PHIN) and CLIC Drive Beam Photoinjectors

Parameter	**PHIN/CTF3**	**CLIC**
Charge / bunch (nC)	2.3	8.4
Train length (µs)	1.2	140
Bunch rep. rate (GHz)	1.5	0.5
Number of bunches in train	1800	70000
Macro pulse rep. rate (Hz)	5	50
Charge / train (µC)	4.1	590
Beam current / train (A)	3.4	4.2
Bunch length (ps)	10	10
Charge stability	<0.25%	<0.1%
Cathode lifetime (h) at QE > 3% (Cs_2Te)	>50	>150
Norm. emittance (µm)	<25	<100

PHIN PHOTOINJECTOR

The PHIN photoinjector is installed at an off-line test stand at CERN (Fig. 1). It consists of a 2.5 cell cavity operated at 3 GHz and two solenoids, which provide the focusing of the electron beam. A test beam line is available with various diagnostic elements for beam measurements. The electron beam is produced by illuminating Cs_2Te or Cs_3Sb photocathodes with an ultra-violet (UV) or green laser beam respectively, which is generated by a powerful Nd:YLF laser system [5].

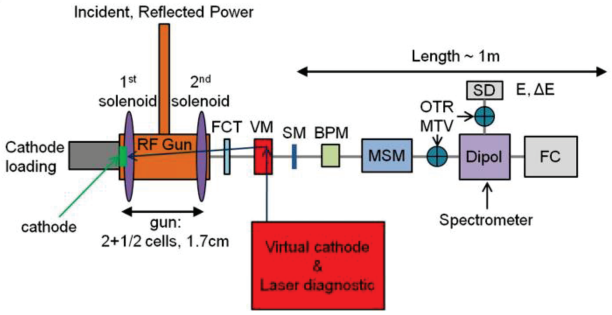

Figure 1: Layout of PHIN. Fast current transformer (FCT), vacuum mirror (VM), steering magnet (SM), beam position monitor (BPM), multi-slit mask (MSM), optical transition radiation screens (OTR), gated cameras (MTV), segmented beam dump (SD), Faraday cup (FC).

SYSTEM IMPROVEMENTS AT PHIN

Vacuum System Upgrade

One main challenge for the CLIC drive beam photoinjector is to achieve reasonably long cathode lifetimes during operation with high peak and average current. While the CLIC time structure cannot be produced at PHIN, it is foreseen to extend the train length beyond the PHIN specifications to the maximum klystron pulse length of ~5 µs. With the maximum available klystron power a maximum bunch charge of 2.7 nC for this operation mode has been estimated, which corresponds to 1.3e14 electrons in the train. Since the resulting beam power of 520 W is too high for the installed uncooled Faraday cup, a study to replace it by a window and a Faraday cup operated in air has been carried out. This study came to the conclusion that only a Beryllium window can withstand this beam intensity [6]. This is planned to be installed in 2015.

In parallel the vacuum in PHIN has been improved in several steps, because the cathode lifetime depends strongly on the vacuum level:

- The NEG coating in a chamber surrounding the gun cavity has been activated. This leads to an improvement of the dynamic pressure during beam operation from 4e-9 to 7e-10 mbar.
- An additional NEG cartridge pump with 1000 l/s pumping speed for hydrogen (SAES getters Capacitorr D1000) has been installed at the exit of the gun. This improved the vacuum level further below 2e-10 mbar during beam operation.

The effect of the first step on the cathode lifetime has been studied with Cs_2Te [7] and Cs_3Sb [8] cathodes and results in a factor 7 of improvement of the lifetimes for both cathode types. With the second step a further improvement is expected, but no conclusive results have been obtained yet.

Charge Stability

Another important parameter for CLIC and CTF3 is the charge stability, which is the only parameter of the PHIN specification, which has not yet been achieved. Charge stability is basically determined by the intensity stability of the laser system, therefore a feedback stabilization loop for the laser beam has been implemented. The scheme (Fig. 2) consists of a photodiode, whose signal is processed by a PID controller. After amplification the signal drives a Pockels cell, which controls the laser beam intensity.

With this feedback loop, the intensity and charge stability of the laser and electron beams could be both improved by a factor 3 down to 0.43% rms and 0.97% rms, respectively. This result is still above the PHIN specification of 0.25%, because the bandwidth of the feedback signal is limited to 1 MHz by the Pockels cell. However, the laser oscillator generates high-frequency intrinsic noise in the range of a few 100 MHz, which cannot be corrected by this feedback loop. This issue might be solved by a new oscillator, which will be described in the next section.

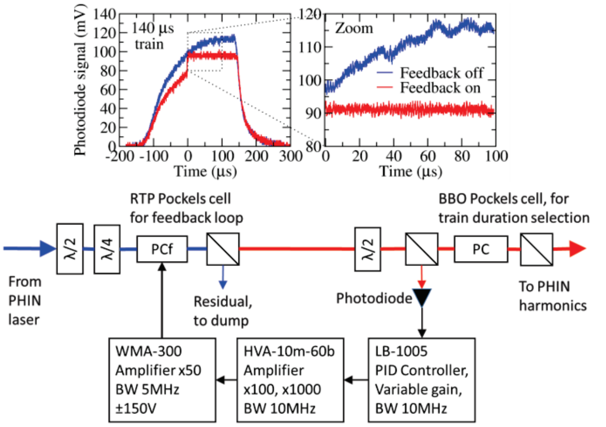

Figure 2: Intensity feedback stabilization scheme. The unstabilized and stabilized laser beams and their signals are shown in blue and red color respectively.

Laser System Upgrade

For the CLIC drive beam photoinjector, also the laser system is challenging. A known issue is the frequency conversion to UV for 140 µs long trains. This problem could be avoided, if photocathodes sensitive to green light like Cs_3Sb are used. Other potential issues might be e.g. the durability of the laser rods during 50 Hz operation and thermal lensing in the laser rods. To study in details the performance of the laser system for CLIC, a new front-end with full CLIC specification has been ordered (OneFive Genki – 10 XP burst). It consists of a 1047 nm mode-locked fiber oscillator running with 500 MHz repetition rate and fiber amplifiers capable to produce bursts with 100 W average power within the burst. It will replace the present front-end (HighQ picoTRAIN) in the PHIN branch of the current laser system and will produce the input for the two main Nd:YLF solid state amplifiers (Fig 3.).

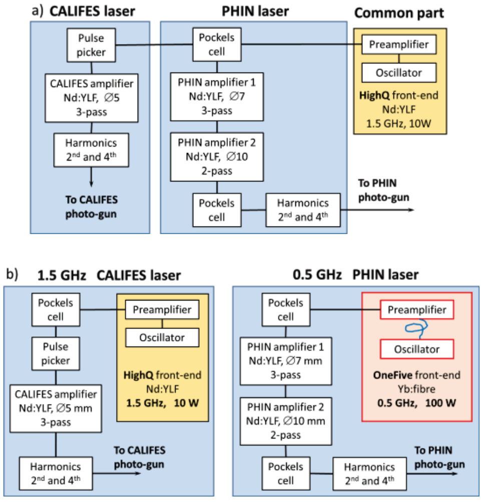

Figure 3: Present (a) and future (b) layout of the CTF3 laser system.

Since the new front-end is based on fiber technology, better intensity stability is expected than the present system has, and it should fulfil the PHIN and CLIC specifications in this aspect. To verify the stability the manufacturer provided for testing purposes a demo oscillator with similar but slightly different specifications than the ordered system has (400 MHz, 1550 nm). The demo oscillator showed a significantly reduced noise spectrum compared with the HighQ oscillator (Fig. 4). An intensity stability of the OneFive demo oscillator of 0.09% has been measured, which opens up the possibility to reach the CLIC specification with the ordered laser system.

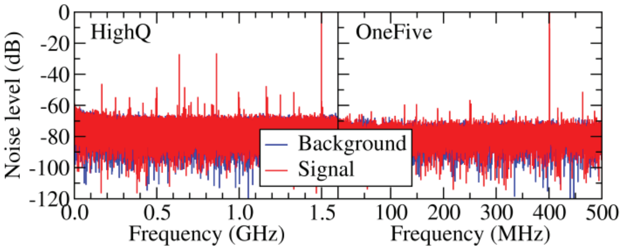

Figure 4: Noise spectrum of the HighQ oscillator (left) and the OneFive demo oscillator (right).

PHOTOEMISSION LABORATORY

The photocathodes for the PHIN studies are developed and produced at the CERN photoemission laboratory by thin film deposition [9]. The cathode production rate is low, because a bake-out of the complete preparation system is required after each change of cathode substrates and evaporators, which is necessary after every three produced cathodes. To overcome this limitation, a study for a load-lock system has been performed. This system should facilitate the exchange of substrates and evaporators and reduce time for this procedure by adding a valve between the manipulator, which holds the evaporator setup, and the preparation system (Fig. 5). This would avoid baking the preparation chamber and limit the baking to the manipulator itself. However, due to space restrictions a complete redesign of the manipulator and attached parts is required.

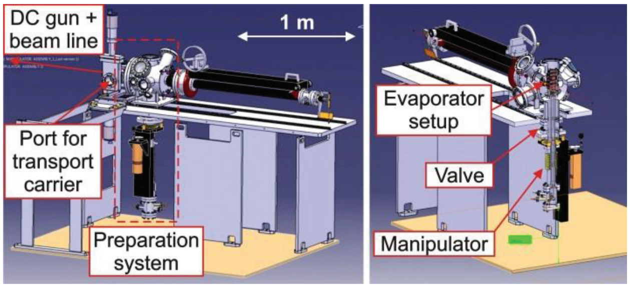

Figure 5: 3D drawing of the cathode preparation system (left) and a cut through the manipulator holding the evaporator setup (right).

For the same reason, there is also no space available to attach directly a load-lock chamber for cathode substrate exchange to the preparation chamber. A possible solution would be the creation of a separate vacuum system to which a load-lock chamber is attached. The transport of the substrates between this system and the preparation system would be done by the existing transport carrier, which is also used for transferring the cathodes to PHIN. Two solutions for this new vacuum system have been studied: The first uses a linear mechanism for holding the substrates while the second uses a wheel (Fig. 6). The second option has the advantage of permitting to add a chamber for long-term storage of photocathodes under ultra-high vacuum conditions.

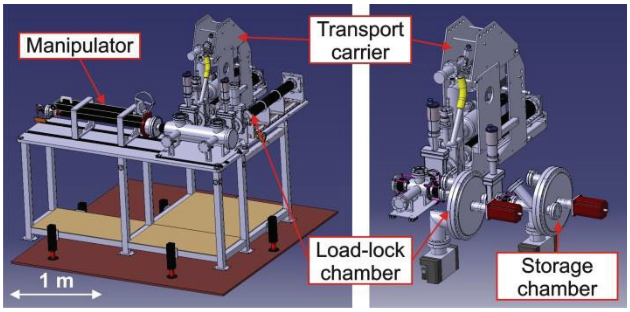

Figure 6: Two options for the load-lock system for cathode substrate exchange: System using a linear mechanism (left) and a wheel (right) for holding the substrates.

CONCLUSION AND OUTLOOK

Efforts for improving the PHIN parameters towards CLIC requirements are on-going. While the feasibility studies for the CLIC laser system seem possible to be completed with the new front-end, it is clear that 140 µs long trains cannot be achieved with PHIN. For the full experimental verification of the feasibility of the CLIC drive beam photoinjector therefore a new dedicated 1 GHz RF gun is needed, which is currently beyond the scope of the CLIC budget.

ACKNOWLEDGMENT

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