PHOTOCATHODE STRESS TEST BENCH AT INFN LASA

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Abstract

In the framework of the preparatory activities to the BriXSino project, a test bench for testing Cs_2Te photocathodes at 100 MHz laser repetition rate has been installed at INFN LASA. This high repetition operation mode is foreseen to be the base operation mode of BriXSino and qualification of the Cs_2Te photocathodes is a key component. While we are not at full specification due to the limited High Voltage of the present DC gun, we discuss the status of the test bench and the initial results.

INTRODUCTION

High brightness electron sources are at the heart of a new generation of x-ray sources based on the Free Electron Laser (FEL), as well as in Energy Recovery Linacs (ERL) and Inverse Compton Scattering (ICS) sources.

These electron sources consist of a photoinjector composed of a laser-driven photocathode exposed to intense electric fields sustained either in an HV DC Gun or in an RF Gun cavity.

The most challenging applications require beams with currents up to 100 mA in a CW (or nearly CW) regime with a repetition rate up to 1.3 GHz.

These final requirements translate into the availability of photocathodes able to sustain this impressive rate of emission as well as drive lasers able to operate up to these frequencies and able to provide nWs per pulse with proper transverse and longitudinal shaping to reduce beam emittance.

It is in this context that our test bench will operate to stress photocathodes and to show that they can cope with such challenging conditions.

BRIXSINO

BriXSino is a reduced scale demonstrator of the modified push-pull folded ERL scheme [1] with maximum energy of the electrons of 50 MeV. In its reduced scheme, only one module will be used both in ERL configuration but also in two-pass mode. BriXSino will also test the loop compression scheme. In the loop, two experimental stations are available for ICS and FEL.

The development of BriXSino's test facility (foreseen at INFN LASA in Milano) aims at maximum energy sustainability by investigating:

- best efficiency in accelerating a high-power electron beam (ERL operation).

- production of very high flux radiation beams (in THz spectral range and in X-rays) for medical applications and applied research in general.

The Conceptual Design Report of BriXSino is now under preparation and it is expected to be published within summer 2021.

Meanwhile, R&D activities are ongoing for electron beams generated from photocathodes with high repetition rate lasers and the development of a Fabry-Perot cavity for ICS applications.

TEST BENCH LAYOUT

The main components of the test bench we are developing at INFN LASA are:

- A DC gun design to sustain 100 kV with a dedicated UHV beamline with diagnostic insertions.
- High voltage and high power components, in particular a 150 kV (at 3 mA) power supply.
- Different photoemissive materials available at the photocathode lab present at LASA.
- A high repetition rate laser able to provide different pulse energies as well as different repetition rates. Figure 1 shows a schematic view.
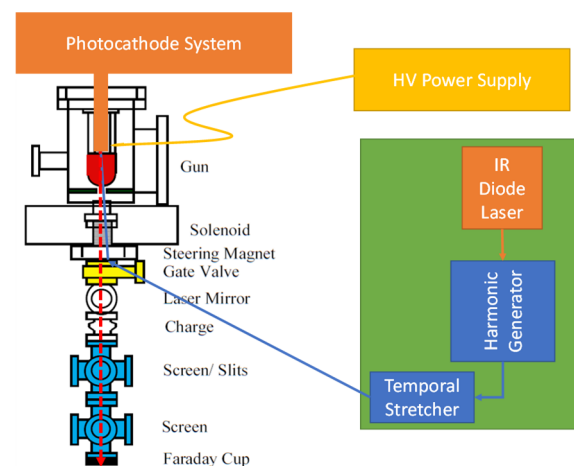

Figure 1: Schematic layout of the photocathode stress bench at INFN LASA.

The INFN LASA Expertise on Photocathodes

INFN LASA has a long-standing expertise on growing and characterization of different photocathode materials sensitive either to UV (Cs_2Te) or to visible light (KCsSb, NaKCsSb, etc.) [2].

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For this stress test, we will start from Cs_2Te that has many interesting characteristics:

- High Quantum Efficiency (emitted electrons per incident photon)
- Good QE uniformity, long operative lifetime
- Low dark current
- Low thermal emittance
- UHV required but more robust to pollution than the visible photocathodes
- Its sensitivity to UV light that poses challenging requirements on the laser both in term of long-time stability of the optical components and in term of energy required for efficient photoemission

LASA produced photocathodes are nowadays used in many high brightness injectors (FLASH, PITZ, APEX, FNAL, LCLS-II commissioning) due to their stability.

In particular, we have developed also all the associated UHV system that allow depositing and exchanging photocathodes between different sites. Moreover, our plug is a standard within the RF gun community.

DC Gun Structure

The DC "gun" uses a pseudo parallel–plate geometry with a removable photocathode, followed by a solenoid to focus the electrons, and a short beamline (0.4 m long) with various diagnostics. All the elements stay on top of an optical table.

The DC high voltage extractor itself is based on a CERN design, modified to accommodate our cathode substrates and to increase the accelerating gradient while maintaining fixed the peak surface fields [3]. This has been achieved by designing the curvature around the extraction hole with an elliptical shape. The same concept has been used to design the cathode region. This modification has reduced by 6 % the Kilpratick limit thus allowing an increase in the maximum accelerating gradient while keeping constant the gap voltage. The nominal maximum voltage is 100 kV across a gap of 8 mm.

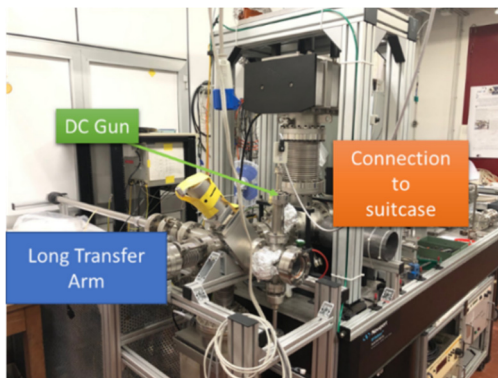A photocathode load–lock unit is used to load and unload the cathodes from our suitcase (see Fig. 2).

Figure 2: Picture of the HV DC gun installed at INFN LASA before its installation in the new Laser Laboratory.

High Voltage Elements

A special designed Heinzinger negative HV power supply (model HNCS) will be used to polarize the cathode. It can deliver up to 150 kV @ 3 mA and is completely remote controlled.

A two meters cable (80 pF capacitance) connects the power supply to the gun. A 1 MΩ resistance in series to the cable is used to limit the accumulate energy. Preliminary tests using higher resistance value (30 MΩ) do not show any significant improvement.

Increasing the applied voltage with respect to the design value of 100 kV would allow to improve the performances of the test bench in term of extractable charge as well as in term of beam dynamic performance.

Laser System

The laser system is based on a 1035 nm mode-locked Yb-fiber oscillator, operating at 92.857 MHz of repetition frequency with a maximum power of 10 W. Starting from the IR light, the radiation is up-converted to the 4th harmonic (258.75 nm) using a double-stage that employing Lithium triborate (LiB_3O_5) and BBO (BaB_2O_4) crystals for the second and fourth harmonic generation, respectively. Since the BBO work in critical phase-matching condition, the generated beam will experience a walk-off process. This effect can be compensated by using three consecutive BBO crystals, rotated oppositely. The expected conversion efficiency of the two stages is 33 and 17 %, respectively, corresponding to a maximum output power of about 3 W at 517.5 nm and 0.5 W at 258.75 nm. The laser repetition rate is variable from 1 MHz to 93 MHz thanks to a Pockels cell driven by an external modulator.
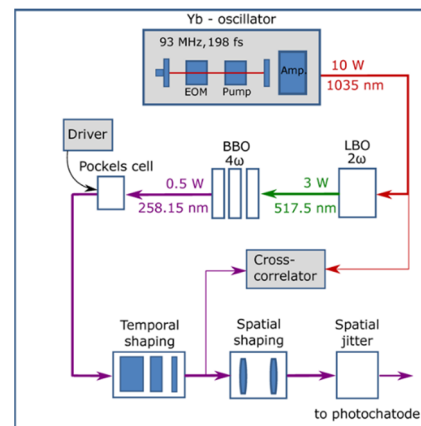

Figure 3: Schematical layout of the laser system able to generate 4th harmonic pulses with a proper time and spatial profile.

Subsequently, the pulses undergo an intensity profile shaping both in the temporal and spatial domain. The first shaping is based on the stacking method and exploits birefringent crystals. The second is performed by a pi-shaper that employs an aspheric lens. Finally, an optical system provides the required spatial jitter stabilization on the photocathode target. A schematic layout of the laser system is reported in Fig. 3.

Based on the laser parameters, the working area of our Stress Test Experiment is reported in Fig. 4 where two QE values are reported along with the corresponding current or charge emitted from the photocathode.

MC2: Photon Sources and Electron Accelerators
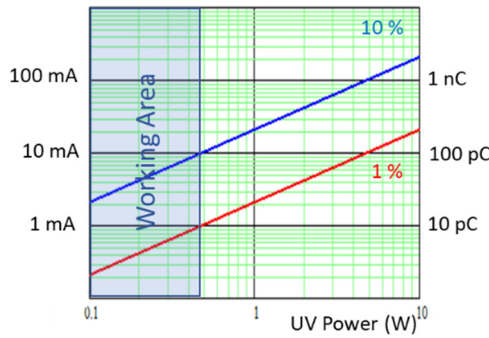
T02 Electron Sources

Figure 4: Expected performance for the Photocathode Stress Test with respect to different QEs values.

BEAM DYNAMICS

Beam dynamics simulations have been performed using code ASTRA [4] and considering both 50 pC and 100 pC extracted bunch charges for a 50 ps flat-top laser time (rise times = 1 ps). The main goal of this study was to investigate the electron bunch size at 0.4 m and its dependence from the laser spot size at the photocathode.

Preliminary simulation results are reported in Fig. 5 where a laser spot size at the cathode of 400 μm gives very similar results for both charges of 50 pC and 100 pC.

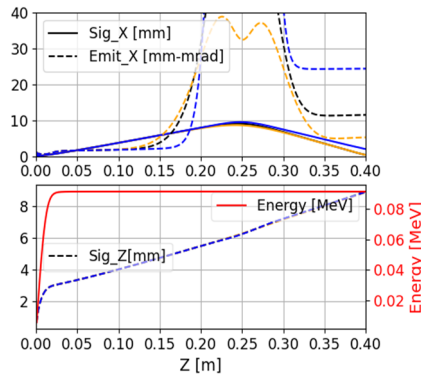Figure 5: The upper plot shows beam emittances (dashed lines) and envelops (solid lines) for three different solenoid maps ($B_{z\_peak} \approx 300$ G). In yellow the longer fringing fields, in black short fringing field, in blue a quasi hard edges fringing field. The lower plot shows the energy gain (in red) and the bunch lengthening (dashed blue) common values for the three maps cases.

EXPECTED PERFORMANCES

The charge extraction mechanism in the DC gun, strongly depends on the emission regime determined by the length of the bunch w.r.t. longitudinal dimension of the accelerating gap.

In the long bunch regime, Child-Langmuir law limits the maximum extractable current density (in case of a parallel plane configuration) according to:

$$J_{Child} = 2.34 \; 10^3 \frac{\Delta V^{\frac{2}{3}}}{d^2} \left[\frac{A}{cm^2} \right] \quad (1)$$

where ΔV is measured in MV and d in cm. Considering the nominal voltage of 100 kV, the maximum current

density achievable is 116 A/cm² that can be increase up to 212 A/cm² if we reach the 150 kV available from the power supply. Assuming a laser spot size of 0.4 mm, the corresponding current at nominal voltage is 500 mA.

In the short bunch regime, the charge extraction is approximated by a charge sheet. The maximum charge density is, in this case, given by:

$$\sigma = \frac{E}{\epsilon_0}$$

where E is the electric field at the cathode and ϵ_0 is the vacuum dielectric constant. Assuming a gap distance of 8 mm, at the nominal voltage the corresponding electric field is 12.5 MV/m and the corresponding charge density is 11 nC/cm². For the same spot size as before, the charge per bunch extractable is 56 pC that, at 100 MHz, corresponds to an average current of 5.6 mA.

In case of our DC gun and pulse length, we are in the transition region between the two regimes. Already a 20 ps of the laser pulse translates into 6 mm spatial laser pulse length that is clearly comparable to the voltage gap of our DC gun. Study this transition region is a further opportunity given by the operation of the DC gun.

CONCLUSIONS

The test bench presented in this paper will be fully operative by the end of 2021. The current situation of the Laser lab is shown in Fig. 6.
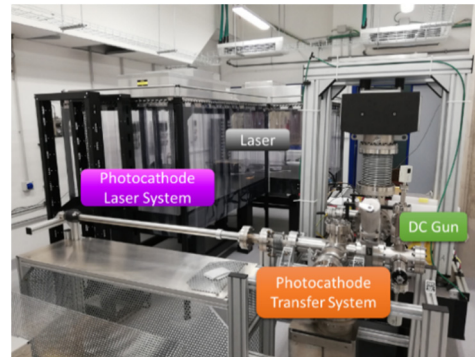

Figure 6: Laser Lab status

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