PHOTOINJECTOR OF THE EBTF/CLARA FACILITY AT DARESBURY

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Abstract

A photoinjector designed for Electron Beam Test Facility (EBTF) and Compact Linear Accelerator for Research and Applications (CLARA), a proposed FEL test facility is described. The photoinjector is based on a 2.5 cell S-band photocathode RF gun operating with a copper photocathode which is driven by a third harmonic of Ti: Sapphire laser (266 nm) installed in dedicated thermally stabilized room. The injector will be operated with laser pulses with energy of up to 2 mJ, a pulse duration of 80 fs RMS and initially a repetition rate of 10 Hz, with the aim of increasing this eventually to 400 Hz. At a field gradient of 100 MV/m provided by a 10 MW klystron, the gun is expected to deliver beam pulses with energy of up to 6 MeV. Bunch length and emittance of electron bunches essentially depend on the bunch charge and vary from 0.1 ps at 20 pC to 5 ps at 200 pC and from 0.2 to 2 mm·mrad respectively. Additional compression of the electron bunches required for CLARA will be provided with a velocity bunching scheme and a dedicated chicane.

INTRODUCTION

The Electron Beam Test Facility (EBTF) is a 6 MeV electron accelerator designed to provide low emittance, short pulse beams to two user stations [1-2]. It will also act as the front end for the proposed CLARA accelerator [3-4]. Initially, the beam for EBTF will be delivered by a 2.5-cell, S-band, normal-conducting, RF gun originally designed for the ALPHA-X project [5].

The front end of EBTF (Fig. 1) has been designed as a photoinjector diagnostics suite to fully characterise 6D phase space of bunches. A variety of YAG screens and slits will be used to characterise the beam transversely. Longitudinal characterisation of the beam will be provided with energy spectrometer comprising a dipole magnet and a YAG screen. Bunch length will be measured using a Transverse Deflecting Cavity (TDC) [7] to streak the longitudinal position of the particles onto the transverse plane, thus making it viewable on the YAG screen. Furthermore, if the streak is performed in the vertical plane as planned, then passing the beam around the horizontal spectrometer will make the longitudinal phase-space directly viewable on the screen. Combining the TDC with the transverse beam diagnostics will allow time-sliced emittance measurements to be made. For better thermal stability the injector is mounted on an artificial granite support.

PHOTOINJECTOR BEAM DYNAMICS

The EBTF photoinjector has been modelled both in ASTRA and GPT. The simulations presented are at the maximum bunch charge of 250 pC to show the effects of space charge. For the simulations, an intrinsic emittance of 0.9 mm·mrad per mm RMS beam size is used [6]. The simulations presented here are based on the factory measured laser pulse length of 80 fs RMS. An optimisation of the photoinjector beam line was performed looking at the beam parameters at 1, 3, and 10 m from the photocathode to observe their evolution, as shown in Fig. 2. It was found that energy spread is highly sensitive to solenoid strength due to space charge. The energy spread could be controlled by operating further off-crest in the gun, at a phase of -35° from that of maximum energy gain.

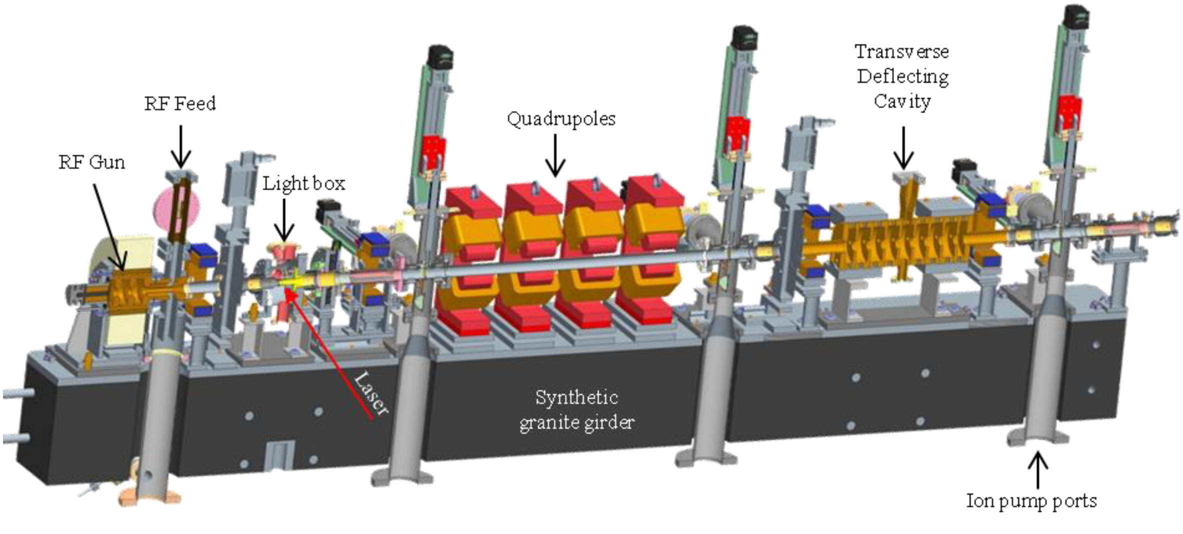

Figure 1: CAD drawing of the EBTF photoinjector

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To use the TDC for the bunch length diagnostic, four quadrupoles are located before it and are used to minimise the beam size in the streak plane, whilst keeping both transverse beam sizes relatively constant, as shown in Fig. 3. Minimising the transverse beam size reduces the energy spread increase when passing through the TDC, because longitudinal electric field, zero on axis of the TDC, increases linearly with distance from the axis. Since the TDC also gives, due to imperfectly matched electric and magnetic fields, an offset to the beam as well as a streak, , corrector coils are used either side of the cavity to keep the beam on axis. Fig. 4 shows the optimised particle trajectories from the cathode through the TDC to the screen.

PHOTOINJECTOR RF SYSTEM

To provide the required 6 MeV beam energy for the EBTF RF gun a K2 ScandiNova klystron modulator capable of providing 250 kV, 150 A pulses of up to 3 µs at a repetition rate between 1–400 Hz, has been procured and recently commissioned.

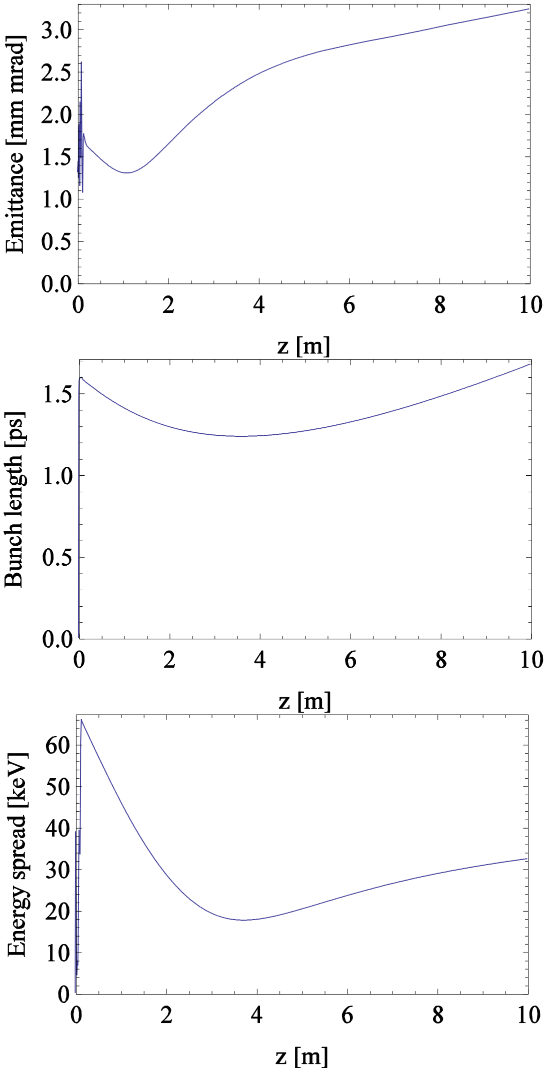

Figure 2: Evolution of beam parameters up to 10 m.

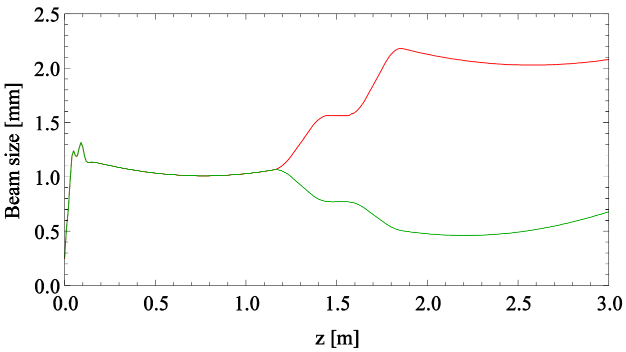

Figure 3: Horizontal (red) and vertical (green) beamsizes through the transverse deflecting cavity.

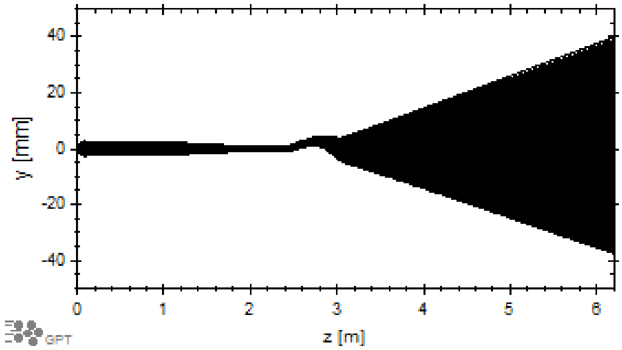

Figure 4: Vertical trajectories with the transverse deflecting cavity providing a streak.

The modulator is used to power a Thales TH2157 klystron capable of providing a peak RF output power of 10 MW at 2998.5 MHz and will be operated at a repetition rate of 10 Hz for the EBTF RF gun. For a 3 µs pulse width the modulator is designed to maintain a voltage stability of ±0.1 % with a 1 µs peak voltage top flatness of ±0.1 %. During the modulators acceptance tests jitter measurements were performed; the pulse to pulse jitter was ±1.3 ns and the pulse width jitter was ±2.7 ns.

The low level RF (LLRF) system for EBTF will consist of an ultra-stable and low noise master oscillator produced by RALAB AG, which will output locked frequencies to drive the laser and RF system. Reference distribution between the oscillator and the RF system at a frequency of 2998.5 MHz will be via temperature stabilised dielectric cables (LCF38-50J). To minimise the effect of temperature change during operation, these cables will be held at 24±0.1°C, a region where they are particularly stable.

The LLRF control of phase and amplitude for the RF gun will be via an in house built digital LLRF control system using heated and temperature stabilised RF front ends, a LLRF 4 FPGA control card [9] and a remote calibration system which will measure and correct for errors on a slow control loop as environmental factors change. Thus it will be possible to correct for pulse to pulse errors using this system and expect to achieve 0.1% amplitude and 0.1° phase stability and be able to compensate for environment changes on the machine over the period of the day. Additionally the temperature of the RF gun will be stabilised to ±0.1°C to ensure that it is maintained at its operating frequency.

PHOTOCATHODE AND DRIVE LASER

The photocathode is a polycrystalline, oxygen-free, copper disc (Fig. 5), polished to 1µm roughness. It forms an integrated part of the 2.5-cell gun cavity and is placed at the back wall of the first half-cell. Prior to installation the cathode is degreased by washing in acetone, ethanol and finally in de-ionized water (>10 MΩ). Carbon contamination is then removed from the surface by ozone cleaning. The gun is pumped down and baked to 150°C in order to achieve pressure in the region of 10^{-10} mbar. The emission area of the photocathode plate is locally baked to a temperature of 200°C to remove oxide.

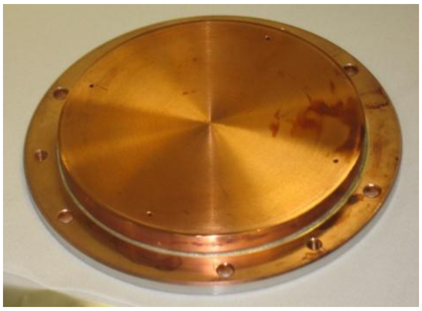

Figure 5: The photocathode of the EBTF gun.

Future developments will look at the use of higher quantum efficiency photocathode materials like single-crystal copper and other metals such as Mg, Pb, and Nb. For Cu and Nb, high-purity metal discs of 10 mm diameter and 2 mm thickness will be inserted into the cavity wall, whilst Mg will be directly deposited onto the wall surface.

The photocathode will be driven by a frequency-tripled Ti:Sapphire laser system with a repetition rate of up to 400 Hz. The pulse energy at 266 nm is 2 mJ and the pulse duration is 80 fs RMS, giving a peak power of ~10 GW. As generated, 99% of the pulse energy is contained within a beam diameter of 20 mm and so the beam intensity is ~2 GW/cm^2. The intention is to focus the UV beam to a spot size of ~1 mm FWHM on the cathode, which will increase the beam intensity to nearly 1 TW/cm^2. Significant difficulties in the transport of the full beam power will be encountered and early operation will be likely at reduced power.

To prevent beam disruption through non-linear effects, as much of the ~14 m long transport path as possible will be in vacuo and no refractive optics will be used; all beam focusing will be done with mirrors. One air to vacuum window will be required in the laser room at the entrance to the vacuum system and this will be made from calcium fluoride to prevent two-photon absorption (TPA). The laser transport vacuum will be isolated from the gun vacuum by differential pumping so that no window will be required where the beam intensity is at its highest.

The very high beam intensity also leads to a high risk of damage to the optics. All but the final mirror will have a standard ultra-fast, multi-layer dielectric coating with a high damage threshold. The final mirror sits in the gun vacuum and has a simple protected aluminium coating on a copper substrate to prevent damage from accumulated electrical charge. The photon damage threshold of this mirror will be found experimentally.

CONCLUSION

EBTF photoinjector is being installed presently at Daresbury laboratory (Fig. 6).The first commissioning stage is scheduled to begin around November-December 2012.

Figure 6: EBTF photoinjector in the assembling stage.

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