THE COMMISSIONING OF THE EBTF S-BAND PHOTO-INJECTOR GUN AT DARESBURY LABORATORY

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Abstract

The first stage of the installation of the Electron Beam Test Facility (EBTF) at Daresbury Laboratory has been completed and a commissioning phase is presently underway. At the heart of the machine is a two and a half cell S-band RF gun photo-injector incorporating a metallic photocathode, which is capable of delivering 4-6 MeV, low emittance, short pulse electrons (10 - 250 pC). The photo-injector is driven by a UV laser operating at 266 nm wavelength and is powered by a high power RF system incorporating a klystron modulator. This paper describes the commissioning and conditioning of the photo-injector gun.

INTRODUCTION

The Versatile Electron Linear Accelerator (VELA), formally the Electron Beam Test Facility (EBTF) is presently under construction at Daresbury Laboratory [1]. VELA is designed to provide a 4 – 6 MeV beam of electron bunches at charges between 10 - 250 pC with low transverse emittance and short bunch length to two separate user areas and will have an advanced diagnostics section to enable the beam parameters to be characterised in different charge regimes. The first stage of construction has been completed and consists of an S-band RF photo-injector gun (Fig. 1), a high power pulsed klystron modulator, a frequency-tripled Ti:Saphhire laser system with a pulse energy of 2 mJ at 266 nm., and a beam diagnostic section comprising of a wall current monitor, 2 YAG screens, and a Faraday Cup.

The photo-injector is based on the design developed by Eindhoven University of Technology [2] and was built by Laboratoire de l'Accélérateur Linéaire (LAL), Orsay for the Advanced Laser-Plasma High energy Accelerator towards X-rays (ALPHA-X) project [3]. It has been provided to Daresbury Laboratory by Strathclyde University and is a 6.5 MeV (equivalent to an accelerating gradient of 100 MV/m), 2½ cell, standing wave cavity which operates in the π mode, its parameters are shown in Table 1. One of the specific features of the design of the cavity is that it has elliptical cells so as to reduce the level of dark current. The cavity frequency is set and maintained by means of a water jacket, which surrounds the cavity and is designed to operate between 30 and 45°C and is controlled to ±0.1°C. Cold tests performed on the cavity prior to installation showed that the frequency tuning rate of the cavity was 48.8 kHz/°C.

The cavity is surrounded by a solenoid and has a bucking coil to ensure that the magnetic field at the plane of the cathode is zero. The cavity has a removable back plate to allow the cathode to be exchanged. For the initial commissioning of the VELA facility, a copper photo-cathode has been installed that has been plasma treated.

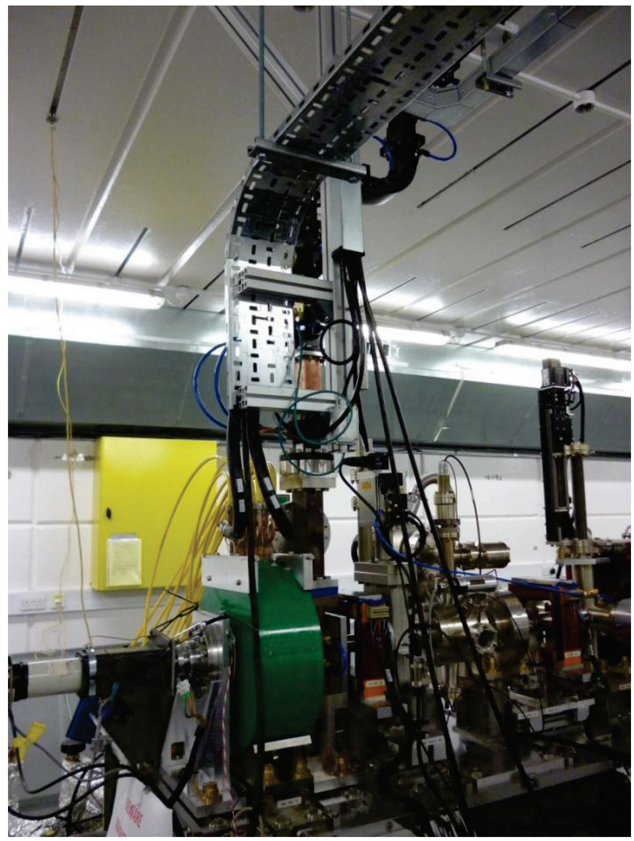

Figure 1: VELA photo-injector gun and solenoid.

Table 1: VELA Photo-injector Parameters

Parameter	Value	Units
Frequency	2998.5	
Bandwidth	< 5	MHz
Maximum beam energy	6	MeV
Maximum accelerating field	100	MV/m
Peak RF Input Power	10	MW
Maximum repetition rate	10	Hz
Maximum bunch charge	250	pC
Operational Temperature	30 - 45	°C
Input coupling	WR284	

THE RF SYSTEM

The RF power to the photo-injector cavity is provided by a Thales TH2157 klystron, which is incorporated in a ScandiNova K2 klystron modulator (Fig. 2) and is located

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on the roof of the VELA facility. The klystron operates at 2998.5 MHz and is capable of providing a peak RF power of 10 MW and an average power of 3 kW (factory settings). The modulator consists of a number of parallel solid state IGBT switching modules, which provide the primary voltage to a pulse step-up transformer and is capable of providing a 250 kV, 150 A flat top pulse of 0.5 – 3 μS at a pulse repetition rate between 1 – 400 Hz, with rate of rise for the pulse of between 150 – 215 kV/μs. During the factory acceptance tests of the modulator the pulse to pulse jitter has been measured at ±1.3 ns and the pulse width jitter was measured at ±2.7 ns.

For the Thales klystron the beam pulse has been set to 167 kV, 119 A, and the repetition rate limited to 10 Hz, due to the operational limitations of the photo-injector cavity.

Figure 2: ScandiNova K2 klystron modulator.

PHOTO-INJECTOR CAVITY COMMISSIONING

Prior to the complete installation of the RF system, the klystron modulator was separately commissioned with the klystron output fed into an RF water load via a circulator and powered to a peak RF power of 10 MW with an RF pulse width of 3 μs and at a pulse repetition rate of 10 Hz.

Additionally, prior to commencement of commissioning the photo-injector cavity was baked to 120°C to remove any water content and to improve the vacuum of the cavity. The cavity temperature set point was adjusted to provide the desired cavity operating frequency of 2998.5 MHz. A waveguide transition between the klystron and cavity was then connected and pressurised with SF6 to 1 bar.

For first electrons it was estimated that an accelerating voltage of around 4.5 MeV, equivalent to a gradient of 70 MV/m was required. To achieve this required gradient it was necessary to condition the cavity to greater than 5.0 MW, thus a power level of 6.0 MW with a pulse width of 2 μs was set as a target.

Initial attempts to condition the cavity were unsuccessful due to successive failures of the quartz RF window. In both cases the baseline vacuum pressure during conditioning was around 2.5×10^{-8} mbar and an RF power level into the cavity of greater than 5.0 MW at a pulse width of 2 μs had been achieved. The first failure occurred after repeated vacuum trips, a rise in the baseline vacuum pressure, along with a degradation of the RF power which eventually led to the window cracking. Additionally, before conditioning could be attempted with the second window it was necessary to re-process the cathode. The second window failure (Fig. 3) occurred more unexpectedly, but was after an increase in RF power.

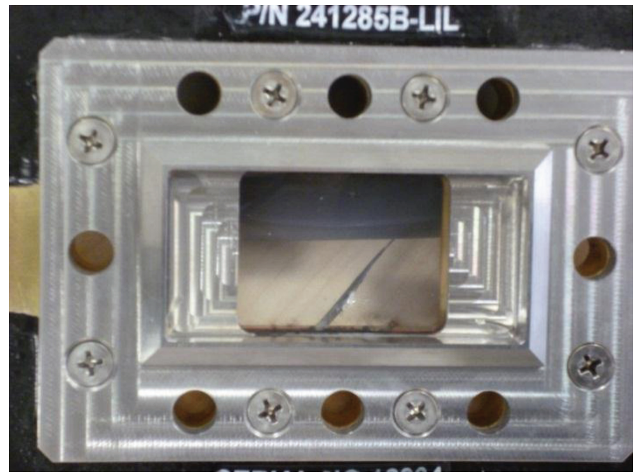

Figure 3: Failed RF quartz window.

The quartz window was replaced with a ceramic window and the waveguide was re-configured. Conditioning of the cavity was re-commenced with an improved processing procedure. The cavity was conditioned at a pulse repetition rate of 10 Hz, and was initially conditioned to 6.0 MW with a pulse width of 0.25 μs (Fig. 4), which is less than the cavity fill time of 0.30 μs. The baseline vacuum pressure during conditioning was around 2.5×10^{-9} mbar, which was an order of magnitude better than was achieved during the conditioning with the quartz RF windows. The pulse width was increased to 0.5 μs and the RF power was raised gradually to 6.0 MW again. However, it was noted that at <6.0 MW the RF power to the cavity appeared limited.

The pulse width was then gradually stepped up; 1.0 μs, 1.5 μs, 2.0 μs and 2.5 μs, and each time the RF power was gradually ramped up. It was found to be necessary to adjust the cavity temperature to maintain the cavity on tune, as the RF pulse width and RF power level were increased, and the cavity temperature set point was reduced from 29.3°C to 26.3°C. During the conditioning process there were numerous vacuum trips, particularly at the higher pulse widths, however these typically recovered very quickly in the matter of minutes allowing the overall process to progress relatively smoothly. Additionally, throughout the process the baseline vacuum pressure during conditioning gradually improved to around 1.6×10^{-9} mbar (Fig. 5). The RF power under these conditions was limited to 5.7 MW, and an investigation

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revealed that the issue appeared to be due to an oscillation in the RF output from the klystron.

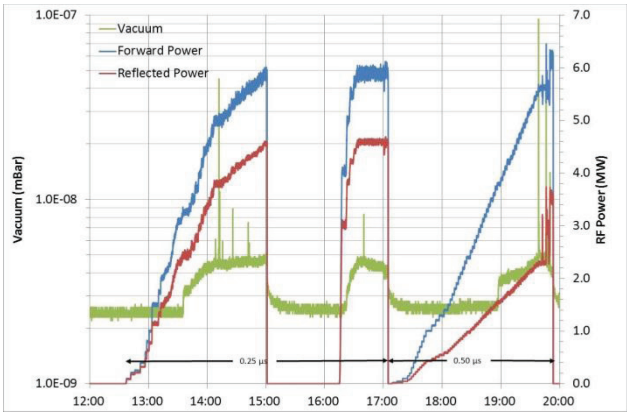

Figure 4: Photo-injector conditioning with a 0.25 µs and 0.5 µs RF pulse width at a repetition rate of 10 Hz.

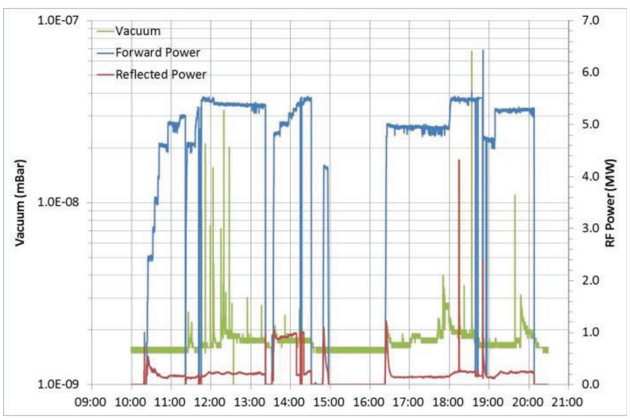

Figure 5: Photo-injector conditioning with a 2.5 µs RF pulse width at a repetition rate of 10 Hz.

Having achieved the required gradient and pulse width the photo-injector laser was aligned onto the copper cathode. The RF power was set to 5 MW and with the laser power set to 1.2 mJ, the timing of the laser pulse with respect to the RF pulse was adjusted and the RF phase was scanned. Eventually evidence of the first electron beam was seen on the first YAG screen (Fig. 6) and was then transported onto the Faraday cup where the charge was measured at greater than 170 pC.

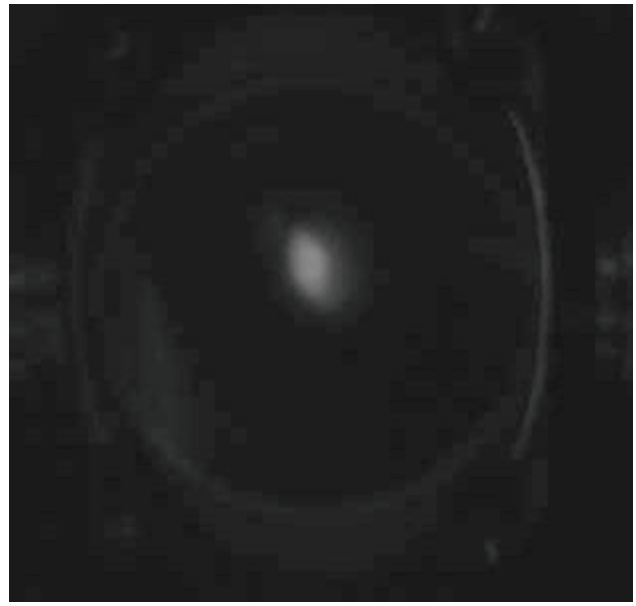

Figure 6: VELA first electrons on YAG screen.

SUMMARY

The VELA photo-injector has been successfully conditioned to 5.7 MW with a pulse width of 2.5 µs and first electrons have been achieved.

Installation of the remaining sections of the VELA facility is now progressing in readiness to provide beam into the two user areas for scientific and industrial applications. Additionally it is planned to investigate the klystron oscillation issues prior to the next stage of commissioning, when it is planned to condition the photo-injector cavity to an accelerating voltage of 6 MeV with an RF pulse width of 3 µs.

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