IMPLEMENTATION AND COMMISSIONING OF THE NEW VERSATILE ELECTRON LINEAR ACCELERATOR (FORMERLY EBTF) AT DARESBURY LABORATORY FOR INDUSTRIAL ACCELERATOR SYSTEM DEVELOPMENT

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Abstract

The Versatile Electron Linear Accelerator (VELA) facility will provide enabling infrastructures targeted at the development and testing of novel and compact accelerator technologies, specifically through partnership with industry and aimed at addressing applications in medicine, health, security, energy and industrial processing. The facility has now been implemented at Daresbury Laboratory and the commissioning of the critical accelerator systems has been performed. The facility is now preparing for first exploitation with partnering industries that will be able utilisation of the electron beam parameters available on VELA to either demonstrate new techniques and/or processes or otherwise develop new technologies for future commercial realisation.

INTRODUCTION

VELA is a new high performance, modular injector facility capable of delivering highly stable, high quality and highly customisable electron beams into a series of dedicated, shielded test enclosures for the development and qualification of advanced accelerator systems [1]. Such a facility will enable industry to expedite their technology development from prototypes to market-ready products, whilst having the potential to revolutionise the application of accelerators in areas of healthcare, security screening, energy generation and industrial processing, whilst also addressing the underlying accelerator technology sub-system challenges in RF acceleration, beam diagnostics, vacuum and magnet systems, optics, accelerator controls and feedback processes. In addition, the high performance capability of VELA is also being developed to explore the fundamental delivery capabilities of next generation compact FEL facilities, as part of the Compact Linear Accelerator for Research and Applications (CLARA) programme at Daresbury Laboratory [2].

The first phase of the VELA accelerator system installation has now been completed and preliminary system commissioning has been initiated, with first electrons emitted from the copper photo-cathode. The next stage of commissioning will facilitate beam delivery into each of the two experimental enclosures for exploitation and further characterisation. Once fully commissioned, industrial users will be able to gain access to VELA to either develop new technologies collaboratively with STFC, or otherwise complete basic proof of concept tests in order to demonstrate advanced technology capabilities for next generation accelerator applications. The supporting STFC facilities, infrastructure, business support and workspace available through the wider Sci-Tech Daresbury Campus (http://www.sci-techdaresbury.com) are intended to further facilitate, support and sustain commercial growth.

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THE VELA FACILITY

The VELA facility comprises an S-Band Photo-injector, which is capable of delivering up to 250 pC of bunch charge at 6 MeV, with micron level beam emittance performance. The copper photo-cathode [3] is driven by a Coherent Inc. UV laser which delivers a pseudo-Gaussian profile of 1 mm FWHM at the cathode. RF power is delivered to the RF Gun via a Thales TH2157A, 10 MW klystron which is powered by a Scandinova K2 modulator, all of which is housed on the VELA injector enclosure roof (see Fig. 1). The electron beam, with delivery specifications identified in Table 1, is then transported through a beam diagnostics line comprising wall current monitor, pepper pot, YAG screens, Faraday Cup and slit/strip line BPMs, with a transverse deflecting cavity (TDC) which is currently under fabrication, before exiting into the two experimental enclosures.

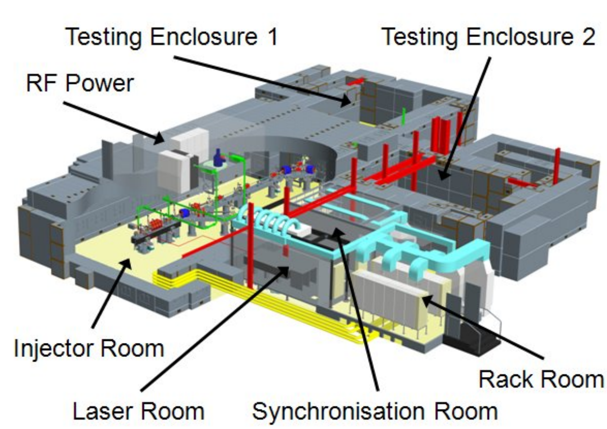

Figure 1: VELA facility layout.

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Table 1: VELA Beam Parameters*

Beam Energy	4 - 6 MeV
Bunch Charge	10 - 250 pC
Bunch length ($\sigma_{t,rms}$)	1 - 10 ps
Normalised emittance	1 - 4 μm
Beam size ($\sigma_{x,y,rms}$)	1 - 5 mm
Energy spread ($\sigma_{e,rms}$)	1 - 5 %
Bunch repetition rate	1 - 10 Hz (Strathclyde Gun) 1 - 400 Hz (future high rep. rate gun in the future; klystron and laser specified for 400 Hz)

**Not all beam parameters are possible to achieve simultaneously. Due to space charge effects, some beam parameters vary along the beam line. Some options of simultaneously achievable beam parameters in the user areas are described in* [4].

Each of the 7 VELA accelerator modules have been assembled, aligned, electrically interfaced, serviced and vacuum leak checked offline, prior to installation on the VELA facility. Fig. 2 shows the completed installation of the photo-injector and diagnostics line modules, ready for first beam commissioning of the photo-injector.

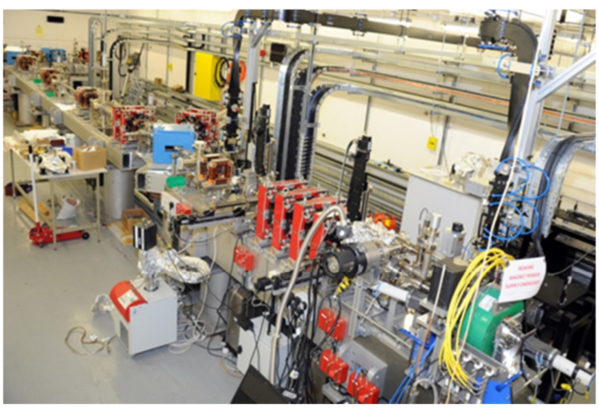

Figure 2: VELA photo-injector module installation.

VELA COMMISSIONING

Both the RF and Laser systems have been commissioned and characterised independently, enabling appropriate levels of RF acceleration and UV laser power to be achieved, prior to exciting the photo-cathode to demonstrate first electrons.

RF Commissioning

The RF Gun is a 2.5-cell S-band, π-mode, standing wave structure, based on the Eindhoven University of Technology [5] design. The device has been provided through collaboration with Strathclyde University [6], which was originally developed for the ALPHA-X laser-wakefield accelerator (see Fig. 3). It is frequency tuned by heating to 30 – 45°C, with a measured tuning rate of 49 kHz/°C. Its temperature is stabilised to ±0.1°C using a dedicated demineralised water cooling supply to minimise tune fluctuations, with primary operating parameters defined in Table 2.

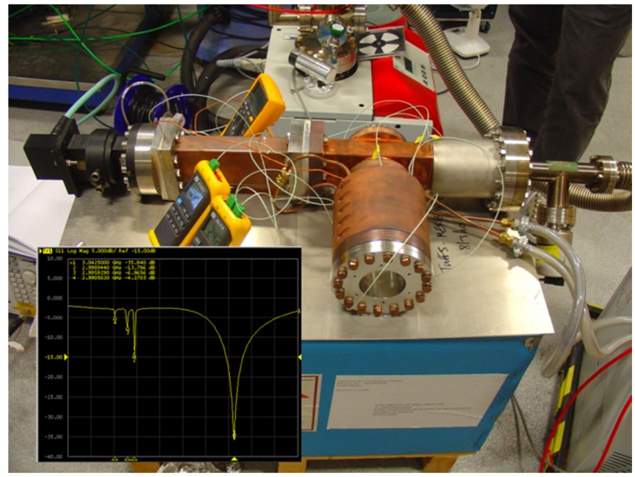

Figure 3: Strathclyde RF Gun, (inset) measured response.

Table 2: VELA RF Gun Parameters

Parameter	Value	Parameter
Frequency	2998.5	MHz
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	

A provisional target of 4.9 MW of cavity power with an RF pulse length of at least 2 μs was identified as the requirement to achieve 70 MV/m field strength, equating to 4.5 MeV acceleration.

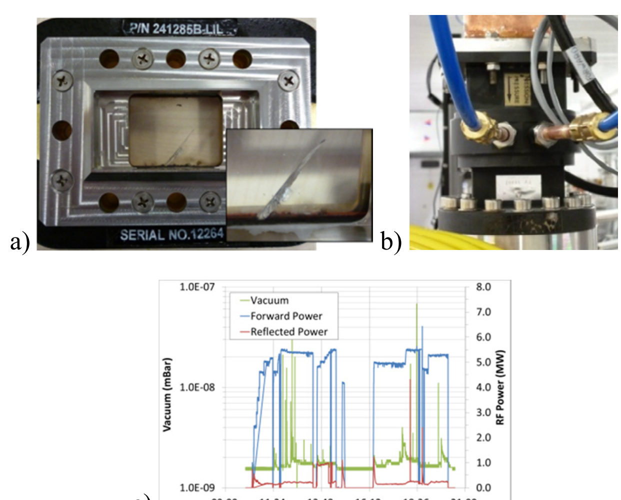

Figure 4: a) Failed quartz window, (inset) window fracture, b) replacement ceramic window and c) RF conditioning results.

RF conditioning was initiated in early Dec 2012 and proved problematic with successive RF window failures, resulting in a technological change from a Quartz-based

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window solution, to a more robust ceramic version (see Fig. 4), which subsequently enabled the RF gun to be successfully conditioned up to the required target parameters in early April 2013 [7].

Laser Commissioning

The photo injector laser source, from Coherent Inc, comprises a 400Hz amplified Ti:S laser operating at a wavelength of 800nm, followed by a frequency tripling stage based on BBO crystals. The drive Ti:S system delivers up to 11mJ at 400Hz, with a pulse duration of 45 fs, with a peak beam intensity of ~1 TW/cm^2. Lower repetition rates are achieved through gating of the amplifier and subsequent pockels cells. The frequency tripling stage has been able to deliver up to 2 mJ of third harmonic radiation, significantly in excess of the original 1mJ specification.

First Electrons

With appropriate RF and laser parameters configured, on Friday 5th April 2013 a first stimulated beam, in excess of 170 pC (electronics saturated) was observed on the first YAG screen monitor, which was then successfully transported to the Faraday Cup positioned at the TDC location on photo-injector module (see Fig. 5).

a) b)

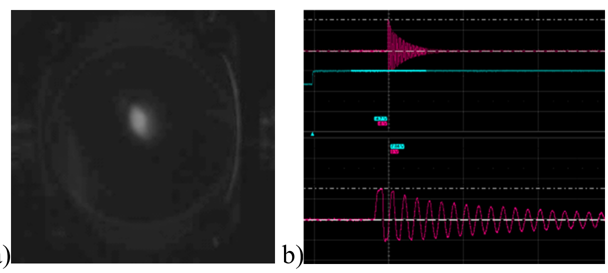

Figure 5: a) First YAG screen beam image and b) signal measured on the Faraday Cup.

Work is now underway to re-configure the temporary laser transport system, which utilised refractive optics and transmission through air, to a more robust in-vacuum system utilising mirrors.

ENGAGEMENT WITH INDUSTRY

VELA is being established as a highly accessible tool, both for commercial and academic users. A unique feature of the facility is that users can access ‘both sides of the wall’ – i.e. the two user enclosures are accessible for exploitation of the beam, and the accelerator itself is accessible for testing of new accelerator components. The potential user community is therefore very broad, including those who wish to use the high-precision pulsed electron beams (or pulsed x-rays produced via conversion targets) for testing or imaging of samples, and developers of accelerator components, controls and beam diagnostics.

Commercial users can access the facility on a pay-per-day basis. STFC can offer the full range of support required by the customer – consultancy on the nature and feasibility of the required tests, design and build of the experimental set-up, assistance with performing experiments, analysis and interpretation of the data. The support package can be tailored depending on the customer’s needs and the complexity of the testing requirements. Additionally, our team can also facilitate access to any other area of STFC’s vast repository of scientific, engineering and computational expertise and facilities. This includes national-scale light source, neutron, laser and supercomputing facilities, plus a vast array of small and mid-range scientific equipment.

Exploitation

Upcoming studies on VELA include:

- Novel security scanning techniques,
- Performance testing components for RF power delivery,
- Testing of novel beam position monitors,
- Evaluation of beam diagnostics technologies,
- Testing and evaluation of beam stabilisation equipment.

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REFERENCES

[1] P. A. McIntosh et al, “A New Electron Beam Test Facility (EBTF) at Daresbury Laboratory for Industrial Accelerator System Development,” IPAC’12, New Orleans, May 2012, THPPR044, p. 4074 (2012); http://www.JACoW.org

[2] J. A. Clarke et al, “CLARA: A Proposed New FEL Test Facility for the UK”, IPAC’12, New Orleans, May 2012, TUPPP066, p. 1750 (2012); http://www.JACoW.org

[3] R. Valizadeh et al, “Preparation of the Polycrystalline Copper Photocathodes for the EBTF RF Photocathode Gun”, MOPFI069, these proceedings.

[4] J. McKenzie et al, “VELA (formerly EBTF) Simulations and First Beam Commissioning”, MOPFI065, these proceedings.

[5] F. Kiewiet et al, “Generation of Ultra-Short, High-Brightness Relativistic Electron Bunches”, Eindhoven University of Technology thesis, ISBN 90-386-1815-8, 2003.

[6] J. Rodier et al, “Construction of the ALPHA-X Photo-Injector Cavity”, EPAC06, Edinburgh, p. 1277 (2006); http://www.JACoW.org

[7] A. E. Wheelhouse et al, “Commissioning of the EBTF S-band Photoinjector Gun at Daresbury Laboratory”, WEPFI065, these proceedings.

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