VELA: A NEW ACCELERATOR TECHNOLOGY DEVELOPMENT PLATFORM FOR INDUSTRY

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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 commissioned at Daresbury Laboratory and the facility is now being actively utilised by industrial groups who are able to take advantage of the variable electron beam parameters available on VELA to either demonstrate new techniques and/or processes or otherwise develop new technologies for future commercial realisation. Examples of which to be presented include; demonstration of a new cargo scanning process, characterisation of novel, high performance beam position monitors, as well as other technology development applications.

INTRODUCTION

VELA is an established 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]. VELA enables industry to expedite commercial technology development from prototypes to market-ready products, having the potential to revolutionise the application of accelerators in areas of healthcare, security screening, energy generation and industrial processing, whilst also developing accelerator technology sub-systems including RF acceleration, beam diagnostics, vacuum and magnet systems, optics, accelerator controls and feedback processes. In addition, its short-pulse capability is also being utilised 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].

VELA is now being actively utilised by industry to expedite technology development activities beyond the inherent capabilities of the associated industrial users. More extensive beam characterisation and transport optimisation has since taken place, the results from which are also highlighted. Further information on what VELA can offer and how access can be obtained, can be found at: http://www.stfc.ac.uk/ASTeC/Business/39928.aspx.

VELA COMMISSIONING

For industrial applications, the most important beam parameters are the achievable momentum (energy) and bunch charge (beam current). Additionally, parameters such as; momentum spread, bunch length, beam brightness (emittance), temporal stability and dark current of the photocathode gun also require characterisation and optimisation.

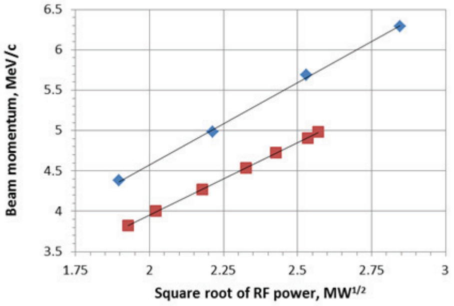

Figure 1: Dependence of beam momentum on RF power (ASTRA simulation – blue, experimental – red).

For measurement of beam momentum and its dependence on the RF power (measured at the RF gun input) and phase of the laser pulse arrival, a spectrometer section is used, comprising a dipole magnet to deflect the beam, a high resolution beam position monitor (BPM) for precise measurements of the deflected beam position, two quadrupoles for beam focusing/optimisation of the dispersion, a YAG screen viewer and a Faraday Cup (FC) for bunch charge characterisation. Varying the RF power & phase, with the beam positioned at the BPM centre, allows measurement of the maximum beam momentum

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with high precision. The dependence of momentum on RF power is shown in Fig. 1, showing that the measured momentum is lower than the calculated momentum with particle tracking and RF simulation codes.

The importance of the bunch charge measurement along the beam line is dictated by the efficiency of the beam transport from the electron source to the VELA user area. Immediately after the gun, the bunch charge is measured with a Wall Current Monitor (WCM) and close to the user areas the charge is re-measured with an Integrated Current Transformer (ICT). Before connecting the user experiment in beam area 1, a temporary FC was installed at the end of the beam line and the sum signal in the adjacent BPM was calibrated with this FC. Fig. 2 shows the dependence of the bunch charge, as measured with the WCM, on the intercepting laser power.

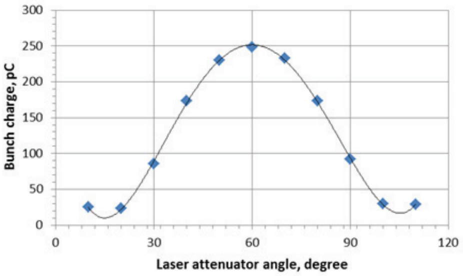

Figure 2: Bunch charge as a function of the laser attenuator angle.

Beam commissioning to date has achieved the specification of 250 pC bunch charge, however the measured beam momentum is low, reaching only ~4.5 MeV/c compared to the design of 6 MeV/c. One of the possible reasons can be attributed to excessive power loss in the RF distribution, which is being investigated. Further details of VELA beam commissioning and description of the measurements of other beam parameters can be found in [3].

TIME-OF-FLIGHT COMPTON SCATTER IMAGING

Rapiscan Systems produce a wide range of security scanning and screening equipment to the civil aviation and cargo handling industries amongst others. In ever more vigilant times, manufacturers of such equipment are continually looking to improve threat detection through enhanced image resolution, full 3D imaging and accurate material identification, whilst the need for increased throughput requires detection systems to be more convenient in terms of installation, simple to use and cost effective in order to promote widespread adoption.

Rapiscan had previously identified Time-of-Flight Compton Scatter Imaging (ToF CSI) as a possible development opportunity. Conventional scanning methods typically rely on transmission imaging where contrast is provided by the attenuation of photons as they pass through objects. This can provide 3D images through tomographic techniques, but requires either the source/detectors or the object to be rotated. It also requires access to both sides of the object. The alternative CSI uses the contrast provided by photons scattering off objects. 3D CSI imaging using the scatter energy-angle relationship is possible but requires either a gamma source or very highly collimated pencil beam of X-rays, neither of which are practical for high-volume screening.

Rapiscan's solution, in collaboration with UCL, combines CSI imaging with ToF information of the photon to recover the point of interaction and provide 3D information about the object. This requires a high flux, high energy beam with extremely narrow pulse widths and advanced diagnostics to successfully image the object. VELA therefore provides the ideal research tool to demonstrate the feasibility of such a technique and close collaboration between STFC and Rapiscan enabled a suitable experimental arrangement and data collection protocol to be devised (see Fig. 3).

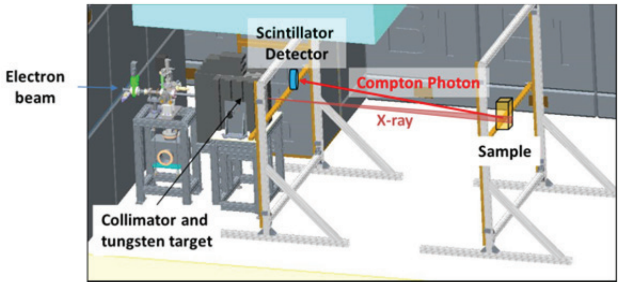

Figure 3: Experimental layout of VELA User Area 1 for ToF CSI.

For the initial feasibility experiments, VELA was used to generate a 10 Hz 4.55 MeV electron beam with an average bunch charge of 100 pC and a pulse length of ~4 picoseconds at the tungsten target used to produce X-rays. A collimator and lead shielding were employed to reduce unwanted background scatter. The photons scattered from a series of test objects were then measured using a fast-response CeBr3 scintillator detector. The sample test objects and scintillator detector were mounted to independent, remotely controlled frames allowing vertical, horizontal and longitudinal translation over metre-scale distances, allowing an extensive map of the scattered signal in a variety of usage scenarios.

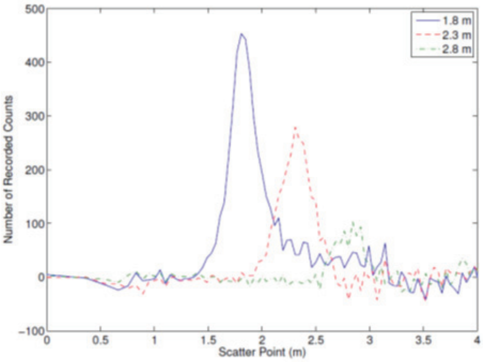

Figure 4: Scatter histogram for detector, with test objects at 1.8 m (solid), 2.3 m (dashed), and 2.8 m (dash-dot).

To simulate cargo, a series of high density polyethylene sheets of varying thicknesses were positioned at a number of longitudinal (z) distances from the target. For these

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initial proof-of-principal experiments, the primary requirement was whether the distance to the target could be determined using accurate ToF and triggering data. The data in Fig. 4 shows processed data with the test objects at three positions relative to the target plane and clearly demonstrates the ability to differentiate between the three data sets. Planning is now underway on the follow-on experiments which will incorporate an improved detection system and will benefit from facility upgrades and improvements to the beam optimisation which have been implemented on VELA in the intervening period.

CAVITY BPM TECHNOLOGY DEMONSTRATION

The Industrialisation of Cavity BPMs is a collaborative project between the Royal Holloway, University of London, FMB Oxford and STFC Daresbury Laboratory. It aims to advance the technology used for sub-μm transverse position measurements in electron linacs to a level suitable for commercialisation. All aspects of the cavity BPM subsystems will be investigated, including the pick-up cavities, analog processing electronics, digitisers, digital signal processing, calibration and stability monitoring. Previous studies [4] have significantly improved the quality of beam based calibrations and overall stability of CBPM systems, hence the development focuses on the hardware, especially on the aspects of consistently high performance, possibly with reduced requirements to tolerances of the cavity pick-ups. Flexibility of the design and its adaptability to different environments and facilities need to be improved, so that it can be used in a wider range of facilities and applications. Another important aspect is the tighter integration of the sub-systems at the component level as well as system level integration, which will facilitate envisaged future commercial use.

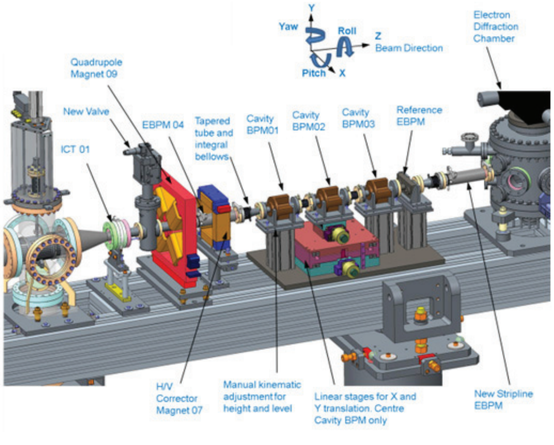

Figure 5: CBPM Layout on VELA.

Simulation and modelling, sub-system prototyping and bench tests, as well as full system beam tests at VELA/CLARA facility are being prepared. The beam setup is the key to the selection process, with a single BPM station now being developed for initial testing of first prototypes. It will be followed by a 3-CBPM setup for a full characterisation of the selected design, including resolution measurements (see Fig. 5). Some of the developed prototypes will later be routinely used as part of the VELA facility, and the product of our development will also become the baseline CBPM design for CLARA.

ELECTRON DIFFRACTION PROCESSES

The ultimate goal is to capture the structure of a material at the atomic level at the speed at which chemical bonds are made and broken. This will have profound impact in many industries, allowing better understanding of, for example, failures in engineering materials (e.g. single crystal turbine blades in jet engines) and drug action in molecular medicine. Time Resolved X-ray Diffraction with X-ray FELS (e.g. XFEL) is the obvious approach. The UK life science community are seeking access to this Serial-femtosecond Crystallography facility. However, small scale electron accelerators such as VELA offer a cost effective alternative of Time Resolved Electron Diffraction. The wavelength of the electron beam in these few-MeV accelerators is actually shorter than the x-ray wavelengths of even the highest energy multi GeV accelerators used for the x-ray FELs. The electron bunches can be made short - a few 10s fs which is the timescale of making and breaking of chemical bonds. Thus collecting a series of diffraction patterns on such a fast timescale will provide details of the dynamics of complex processes. Rather than being an inferior probe, these electrons actually transfer less energy into the sample than x-rays, so sample damage is much less of a problem. A diffractometer will be installed on VELA in summer 2014 with state of the art detection system which will allow single electron detection, allowing weak diffraction patterns to be recorded with ultra-low charge electron bunches. In this first stage, the bunches will be ~100 fs but will be compressed to ~10 fs in subsequent stages [5].

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