A NEW ELECTRON BEAM TEST FACILITY (EBTF) AT DARESBURY LABORATORY FOR INDUSTRIAL ACCELERATOR SYSTEM DEVELOPMENT

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Abstract

Recent UK government funding has facilitated the construction of a unique accelerator test facility which can 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 infrastructure provision on the Daresbury Science and Innovation Campus (DSIC) will permit research into areas of accelerator technologies which have the potential to revolutionise the cost, compactness and efficiency of such systems. The main element of the infrastructure will be a high performance and flexible electron beam injector facility, feeding customised state-of-the-art testing enclosures, and associated support infrastructure. The facility operating parameters and implementation status will be described, along with primary areas of commercialised technology development opportunities.

INTRODUCTION

EBTF is a high performance, modular injector facility capable of delivering highly stable, highly customisable, and high quality electron beams to a series of shielded test enclosures. The new facility and supporting infrastructure will deliver a unique capability in the UK and Europe for the cutting-edge development and qualification of advanced accelerator systems, enabling industry to expedite their technology development from prototypes to market-ready products. In doing so, it has the potential to help revolutionise the use of accelerators in priority areas such as healthcare, security screening, energy generation and industrial processing as well as opening up further high technology commercial markets. Support from industrial companies such as e2v, Rapiscan Systems and Siemens has been secured, as well as scientific collaborative support from both Strathclyde University and LAL, Orsay. In addition, the high performance capability of this electron injector is to be used to explore the fundamental delivery capabilities of next generation compact FEL facilities, with the Compact Linear Advanced Research Accelerator (CLARA) being the principal focus at Daresbury [1].

Construction is continuing apace and EBTF is on schedule to deliver first electrons in December 2012. Following a further period of commissioning and optimisation, industrial usage of this unique facility will then ramp-up from early 2013. Once commissioned, industrial users will be able to gain access to as much or as little 'beam time' and specialist expertise as they require to match specific project requirements, from a basic proof of concept test through to multi-partner, long-term collaborative development programmes. The supporting facilities, infrastructure, business support and workspace available through the wider Daresbury Science and Innovation Campus (DSIC) are intended to further facilitate, support and sustain commercial growth.

THE EBTF FACILITY

The EBTF machine consists of an S-band RF gun photoinjector, delivering 5 MeV, low emittance, short pulse electrons [2] to 2 separate user areas. The machine is housed inside a 2m thick concrete enclosure designed to provide shielding for future higher energy upgrades. Inside the accelerator vault the air temperature is controlled to ±1°C for the optimum performance of the accelerator components and RF signalling cables. Adjacent to the shielding are 3 rooms to house the photoinjector laser, synchronisation equipment and instrumentation racks (see Figure 1), which are also temperature controlled to ±1°C. The photoinjector laser room is a designated clean area, with HEPA MACH 10 laminar air flow units located directly above the laser table. The synchronisation room, which contains the master oscillator for the accelerator, is constructed such that a Faraday cage is formed around the room to remove noise created by potentially harmful external electro-magnetic fields.

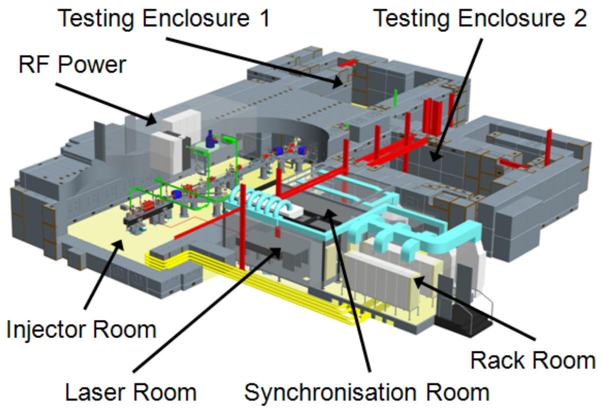

Figure 1: EBTF Facility Layout.

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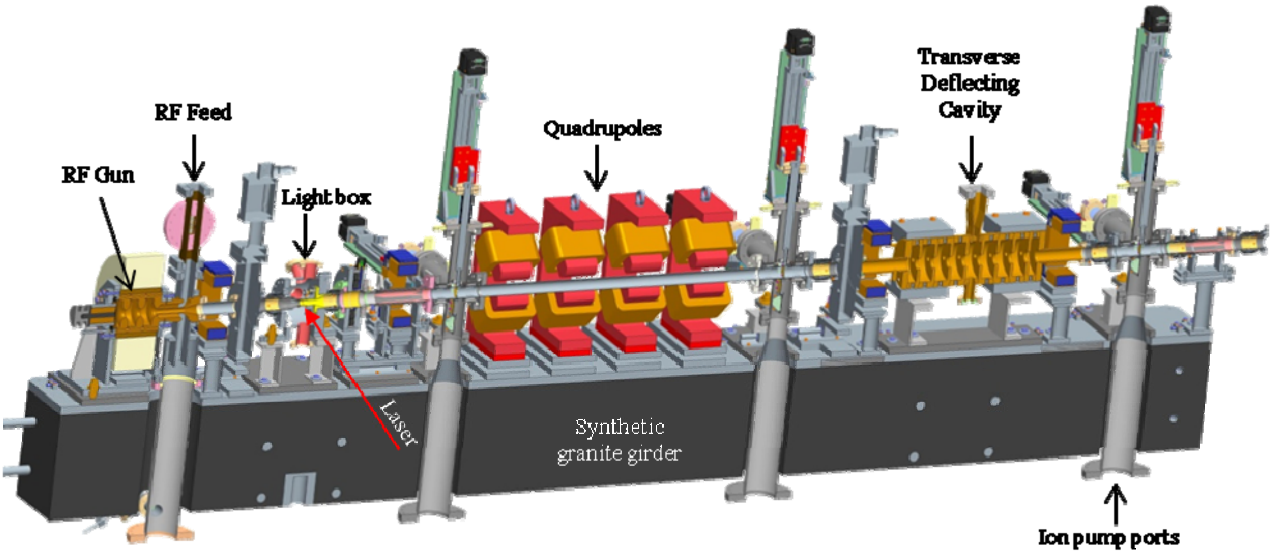

Figure 2: Injection Girder Layout.

Table 1: EBTF 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 (ALPHA-X gun) 1 - 400 Hz (with 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* [3].

Beam source parameters are shown in Table 1, highlighting the flexible beam performance capability proposed for EBTF. Supplementary accelerator infrastructure is also envisaged for each testing enclosure, i.e. beam diagnostics, manipulation systems and feedback control systems. All of these will be configured and routed via a central control room, providing effective beam delivery management for specific testing and development purposes.

ENGINEERING DESIGN CHALLENGES

The primary engineering challenge for EBTF is satisfying the strict stability requirements for the various sections of the accelerator. In addition, magnetic materials cannot be used in close proximity to the beam, as the electron beam energy is relatively low. Consequently, the accelerator components are supported on long aluminium alloy support girders, which gives increased relative stability between components, and reduced time to re-align. Standard aluminium alloy extruded sections are inherently non-magnetic, which have proved to be less expensive than traditional welded steel fabrications. The girders are supported by sand-filled aluminium alloy pedestals giving increased damping against vibration transmitted through the floor. Particularly, noisy equipment will be locally damped at source.

The design of the photoinjector girder is extremely compact with the gun, solenoids, correctors, vacuum valve, light box, wall current monitor, pepper pot, YAG, bellows, slit and strip line BPM all within a 1.2 m section between the cathode and first focussing quadrupole. Vacuum assemblies for the entire machine have been specified such that they are cleaned, baked and gas scanned at their respective suppliers, prior to their delivery to Daresbury. Once assembled, the photoinjector front end will be baked in-situ to achieve the required vacuum specification.

The photoinjector module of the EBTF is supported by a temperature stabilised, synthetic granite girder (see Figure 2). The change in design philosophy for this module is due to the ±28 μm stability tolerance on the length between the RF electron gun and the Transverse Deflecting Cavity (TDC). Synthetic granite was chosen for its low co-efficient of thermal expansion, and its improved vibration damping performance. The RF gun is an S-band, 2.5-cell structure, which has been provided by Strathclyde University [4] and is tuned to the required frequency by heating to 30 – 45°C. This temperature is stabilised to ±0.1°C using a dedicated demineralised water cooling supply to minimise tune fluctuations.

The RF power for the gun is supplied via a Scandinova K2 modulator, powering a Thales TH2157A, 10 MW klystron which is situated in the air-conditioned room on the roof of the shielding enclosure. This allows personnel access while the accelerator is running whilst still maintaining a relatively short RF path length. The RF waveguides for EBTF are temperature controlled with their own demineralised water cooling supply to ±1°C. Also within the RF room on the roof is a Klystron and modulator powering the TDC. The TDC is temperature stabilised to ±0.1°C. Finite Element Analysis was conducted to ascertain the effects of temperature variations on the cavity and optimise the design of the cooling pipes [5].

The gun is driven by UV light at 266 nm wavelength which is generated by frequency tripling an 800 nm Ti:Sapphire laser. In the first instance the transport system will deliver a pseudo-Gaussian profile of 1 mm FWHM at the cathode. With a pulse energy of 2 mJ and a pulse length of 150 fs FWHM, this means the peak beam intensity will be ~1 TW/cm^2 and significant care must be taken to prevent self-phase modulation and self-focusing effects through non-linear interactions and absorption through multi-photon processes. For example, designing a satisfactory window to isolate the transport system vacuum of ~0.1 mTorr from the UHV of the accelerator is a severe challenge. Therefore, a differential pumping system is currently under investigation.

In the laser room the intensity is much lower and the beam will enter the transport system through a calcium fluoride window. Elsewhere, refractive optics will be avoided and the beam compression and focusing will be performed using mirrors and not lenses. The compression will be performed in two stages with one optics box near the entry point of the beam into the accelerator area and the other near the gun itself, where a small amount of the beam will be sent to a "virtual cathode" for real-time monitoring of the beam shape.

Magnets, supplied by Scanditronix will have their magnet centres measured relative to alignment fiducials at the factory. Magnets, vacuum chambers and diagnostic devices will be aligned on each girder to ±50 µm offline. Following successful offline testing the girder modules will be installed accurately within a survey network inside the accelerator shielding using a laser tracker system.

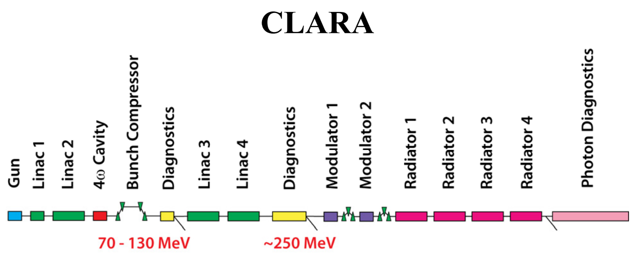

Figure 3: CLARA schematic layout.

A future use for EBTF will be as an injector for a proposed new single-pass national Free Electron Laser (FEL) test facility, CLARA The combined EBTF/CLARA facility layout will remain fully consistent with the continued operation of EBTF as described above. The ultimate aim of CLARA is to develop a normal conducting test accelerator able to generate longitudinally and transversely bright electron bunches and to use these bunches in the experimental production of stable, synchronised, ultra short photon pulses of coherent light from a single pass FEL with techniques directly applicable to the future generation of light source facilities. In addition the facility will be an ideal test bed for demonstrating innovative technologies such as high repetition rate normal conducting RF linacs and advanced undulator designs.

Table 2: Provisional CLARA Parameters

Beam Energy	250 MeV
Undulator Minimum Gap	6 mm
Undulator Period	29 mm
FEL Wavelength	400 – 100 nm
Bunch Charge	20 – 250 pC
Normalised Emittance	0.2 – 2.0 mm-mrad
Seed Sources	800 nm TiSa + Mid-IR OPA + 100 nm HHG
Afterburners	50 nm Novel Technology

The CLARA electron beam energy will be up to 250MeV, which will allow FEL operation at wavelengths from 400 – 100 nm. The design philosophy for CLARA is to build in maximum flexibility to enable the demonstration of many different novel FEL techniques with minimum disruption for reconfiguration. The emphasis will be on the production of FEL pulses of duration less than the FEL cooperation length (typically around 100 wavelengths) for which many schemes have been proposed in the literature but not yet tested experimentally. However, the layout will also be compatible with research and development of seeding and harmonic generation techniques. The provisional parameters of CLARA are given in Table 2 and a schematic layout is shown in Figure 3.

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