OPTICS DESIGN AND LAYOUT FOR THE ELECTRON BEAM TEST FACILITY AT DARESBURY LABORATORY

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Abstract

An Electron Beam Test Facility (EBTF) is being developed at Daresbury Laboratory [1] to provide the beam for scientific and industrial applications and as a front end of FEL test facility under consideration at Daresbury [2]. It is based on a RF photoinjector which delivers a ~6 MeV beam. The photoinjector design in the first phase consists of a 2.5 cell S-band RF gun to be driven by Ti:Sapphire laser. The design is aimed to deliver bunches at 10-250 pC charge with low transverse emittances and ultrashort lengths. The beam transport optics design described in this paper includes a dedicated diagnostics section capable of characterising ultra short and ultra low emittance bunches and beam transport lines to two user areas.

INTRODUCTION

The Electron Beam Test Facility (EBTF) being constructed at Daresbury Laboratory is based on an RF photoinjector designed to provide ~6 MeV energy short beam pulses with low emittance to two user areas [1]. It will also serve as the front end for the proposed Compact Linear Advanced Research Accelerator (CLARA), a free electron laser test facility [2]. 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 [3]. The facility will be built in the experimental area of now de-commissioned Synchrotron Radiation Source at Daresbury Laboratory. This has an advantage of using the available infrastructure and the radiation shielding. The EBTF layout will be modified at a later stage to include accelerator structures to increase the energy as required for CLARA and to manipulate the initial bunch properties. A provision for a by-pass line for the low energy beam has been considered in the design if there will be demand to use a low energy beam in one of the user areas. There are two dedicated beam diagnostics sections; one straight on and one in dispersive region for fully characterising the beam from the RF gun[4].

The beam dynamics and transport of this low energy beam is dictated by space charge, which changes some beam parameters along the beam line. Since there is no specific demand on the beam properties at the user stations as yet, we define a range of possible beam parameters that may be available to the users. The gun phase and gradient, main solenoid and bucking coil settings as well as eventually laser pulse length and spot size can be varied to obtain certain transverse and longitudinal beam parameters in the user areas.

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BEAM PARAMETERS FROM THE PHOTOINJECTOR

The EBTF gun should operate up to a maximum gradient of 100 MV/m, providing maximum energy of 6 MeV at a repetition rate up to 10 Hz. Both the klystron modulator and the laser are rated to operate up to 400 Hz for a future upgrade with a high repetition rate gun. In order to obtain short pulses, the photoinjector laser pulse length has been specified to have a minimum of 40 fs rms with a Gaussian temporal profile, and a choice of copper photocathode has been made. The operating charge will range from 10-250 pC in order to fulfil different industrial applications and later for providing flexible bunch charge for CLARA. This range of charge will also be useful to study the beam dynamics of the photoinjector.

Due to space charge, beam parameters such as energy spread and bunch length vary significantly at higher charge along the beam line in first few meters. In order to transport the beam to the two user areas, it is desirable to have more or less constant beam parameters just before the beam enters first quadrupole located at ~1.2 m from the gun. This is achieved in simulations by optimising laser parameters for different charge operation.

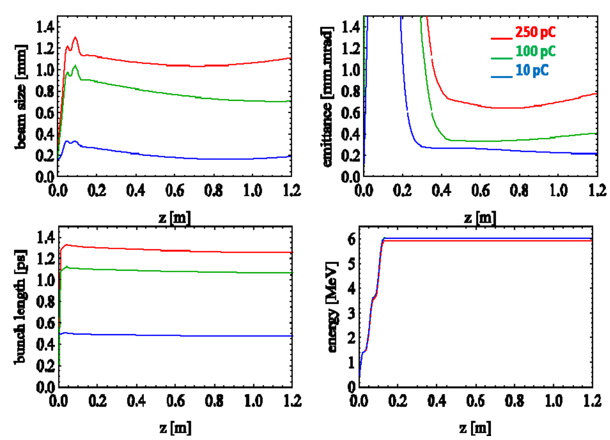

Figure 1: Optimised bunch parameters from the photoinjector up to the first quadrupole.

Fig. 1 shows optimised beam parameters for 10, 100 and 250 pC with laser pulse length 500, 40, 40 fs rms and laser beam diameter of 0.6 mm, 0.6 mm, 1 mm respectively. Gun phase in all the three cases is set at -20° of crest and gradient at 100 MV/m. Solenoid strengths are adjusted to minimise the variation of beam size/emittance before the first quadrupole. The energy spread is not shown here but is not constant and thus has implications to further beam transport to the user areas.

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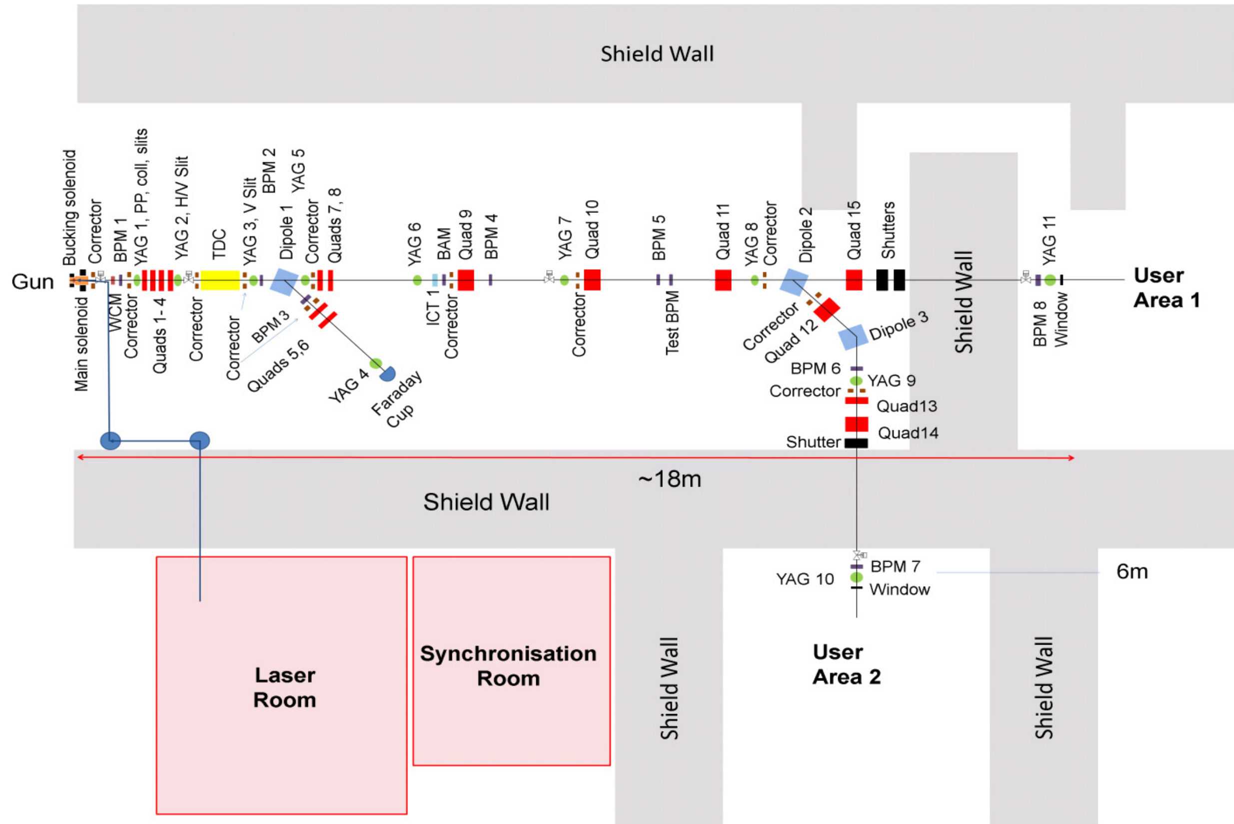

Figure 2: EBTF facility layout.

Facility Layout

The layout of EBTF is shown in Fig. 2. The diagnostics devices placed immediately after the gun include; a Wall Current Monitor (WCM), beam position monitor and YAG screen along with a pepperpot and horizontal and vertical slits, which will measure the beam and current profiles, emittance, bunch charge and beam position. Collimators will be used for cutting down dark current from the gun. The two correctors placed after the gun will be used to centre the beam passing through the dedicated diagnostics section, which consists of four quadrupoles to match the beam profile in the Transverse Deflecting Cavity (TDC). The cavity will streak the beam in the vertical plane and will be used for measuring the bunch length and investigation of the longitudinal phase space in the straight ahead line and the dispersive line following dipole 1. The details of these measurements are discussed in [4]. Dipole 1 bends the beam by 45° and is followed by a quadrupole doublet to optimise the dispersion on YAG4. In the straight ahead line, quadrupoles 7 and 8 are used to control the beam size on YAG6 when characterising the beam. The beam stay clear apertures are chosen as 34 mm diameter in most of non-dispersive regions of the beamline, with larger apertures in the regions before YAG4 and YAG6 to allow the streaked beam to pass without losses.

Beam Transport to User Areas

In addition to quadrupoles 1-4 and 7-8 in the beam diagnostics sections, quadrupoles 9-11 and 15 are available to transport the beam to user area 1. For user area 2, the beam needs to pass through an achromatic bend comprising two identical 45° dipoles similar to dipole 1 in order to bend the beam by 90°, as required to satisfy the building constraints. A range of beam diagnostic devices and correctors have been located in the beam transport lines to both the areas to ensure the required beam parameters are maintained. The beam transport to this area needs to satisfy an additional requirement on energy spread so as not to exceed the beam size in the achromatic section. Two additional quadrupoles, 13 and 14 after the achromat will be used to match the beam parameters to user area 2 in addition to the quadrupoles before dipole 2.

The beam transport to both user areas needs to satisfy two constraints; the maximum transverse beam size ($\sigma_{x,y}$) along the beam line to be kept under 3.5 mm and a transversely round beam with a beam waist at the window in the user area. The beam parameters that can be achieved are somewhat restricted in user area 2 due to space charge as well as initial chirp from the gun in this particular gun setup. Fig. 3 shows beam sizes and longitudinal beam parameters along the beam line for bunch charge of 10 pC and Fig. 4 shows transverse beam profile and longitudinal phase space at both the user

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stations at 10 pC. Fig. 5 and Fig. 6 show the same beam parameters at 250 pC.

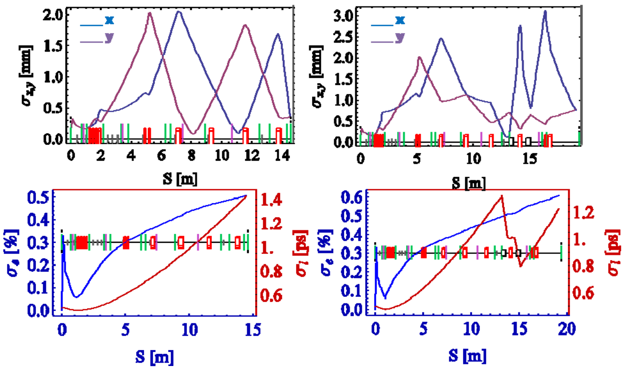

Figure 3: Beam sizes and longitudinal parameters along the beam line to user area 1 (Left) and user area 2 (Right) at 10 pC.

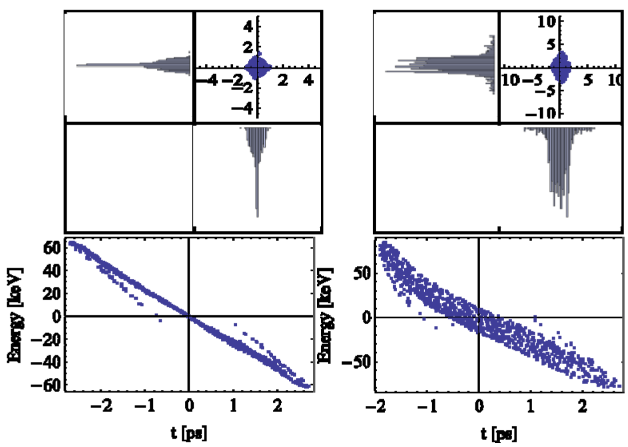

Figure 4: Beam spot and transverse profiles (Top) and longitudinal phase space (Bottom) at user station 1 (Left) and user station 2 (Right) at 10 pC.

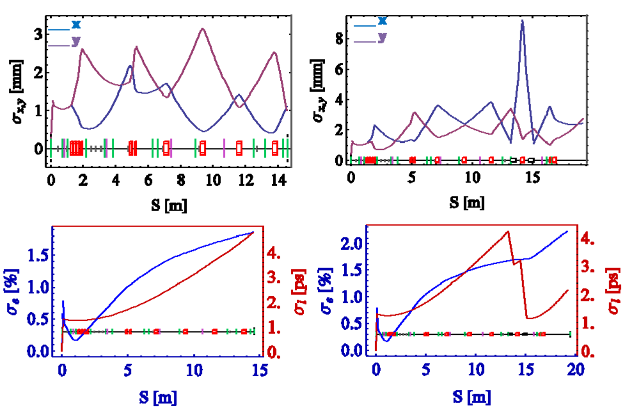

Figure 5: Beam sizes (Top) and longitudinal parameters (Bottom) along the beam line to user area 1 (Left) and user area 2 (Right) at 250 pC.

The achievable beam parameters for low and high charge in two user areas are different due to non-isochronous beam transport through the achromat and a chirped bunch from the gun. There is no control over bunch length in the straight beam line to user area 1 and it continues to grow. At 250 pC, the maximum transverse beam size in the achromat increases to 8 mm (Fig. 5) due to large energy spread. This can be addressed by reducing the chirp from the gun; however this may lead to increase in bunch length. It will be possible to get range of beam waist sizes at the user stations; only one example is shown here.

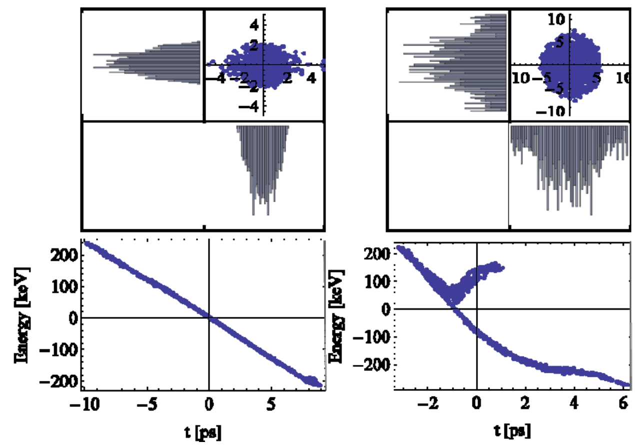

Figure 6: Beam spot and transverse profiles (Top) and longitudinal phase space (Bottom) at user station 1 (Left) and user station 2 (Right) at 250 pC.

CONCLUSIONS

The EBTF facility delivers an ~6 MeV energy beam from a S-band RF gun, and allows for characterising short low emittance bunches. The transport beam line is optimised to deliver the beam to two user areas at different charges between 10-250 pC. Depending upon the user requirements, the gun and the beam line settings can be further optimised either to deliver short bunches or small transverse spot size. Some flexibility in the operation exists to further tailor to the user requirements.

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