

ERLP GUN COMMISSIONING BEAMLINE DESIGN

D.J. Holder, C. Gerth, F.E. Hannon and R.J. Smith,

ASTeC, Daresbury Laboratory, Warrington, WA4 4AD, UK

Abstract

The 4GLS project is a novel next-generation solution for a UK national light source. It is based on an energy recovery linac (ERL) operating at high average beam currents up to 100mA and with compression schemes producing pulses in the 10-100 fs range. This challenging accelerator technology, new to Europe, necessitates a significant R&D programme and a major part of this is a low-energy prototype, the ERLP, which is currently under construction at Daresbury Laboratory, in the north-west of England. The first components of ERLP to be built will be the DC photocathode gun and low-energy beam transport and diagnostics. The gun will initially be operated with a diagnostic beamline in order to measure the properties of the high-brightness beams generated as fully as possible. This will allow comparison of its performance with the results of multi-particle tracking codes, prior to its integration into the ERLP machine. The diagnostic beamline will include diagnostics for measuring the transverse and longitudinal properties of the electron beam.

This paper will describe the design of this diagnostic beamline and demonstrate through simulation, the expected characteristics and performance achievable from this system.

INTRODUCTION

The ERLP uses a replica of the DC photocathode gun used in the IR Demo and Upgrade FELs at Thomas Jefferson National Accelerator Facility (J-Lab), which has already been producing high-brightness, high average-current electron beams [1]. The gun is currently being built at Daresbury Laboratory, and will be operated with a negative affinity GaAs photocathode which will be illuminated with a mode-locked Nd:YVO₄ laser with an oscillator frequency of 81.25MHz. The 350keV electron beam from the gun is transported via a normal conducting buncher cavity and accelerated by a superconducting booster to 8.35 MeV before entering the recirculating section. The fundamental frequency of both the buncher and the booster is 1.3GHz, and are based on ELBE designs [2]. A second superconducting linac module accelerates the beam to 35 MeV before it is then redirected back to the linac (for energy recovery) by the return transport line. The return path incorporates a FEL based on a permanent magnet wiggler (previously used in the Jefferson Laboratory IR-Demo machine) and two dipole chicanes. The layout of ERLP is illustrated in Fig. 1.

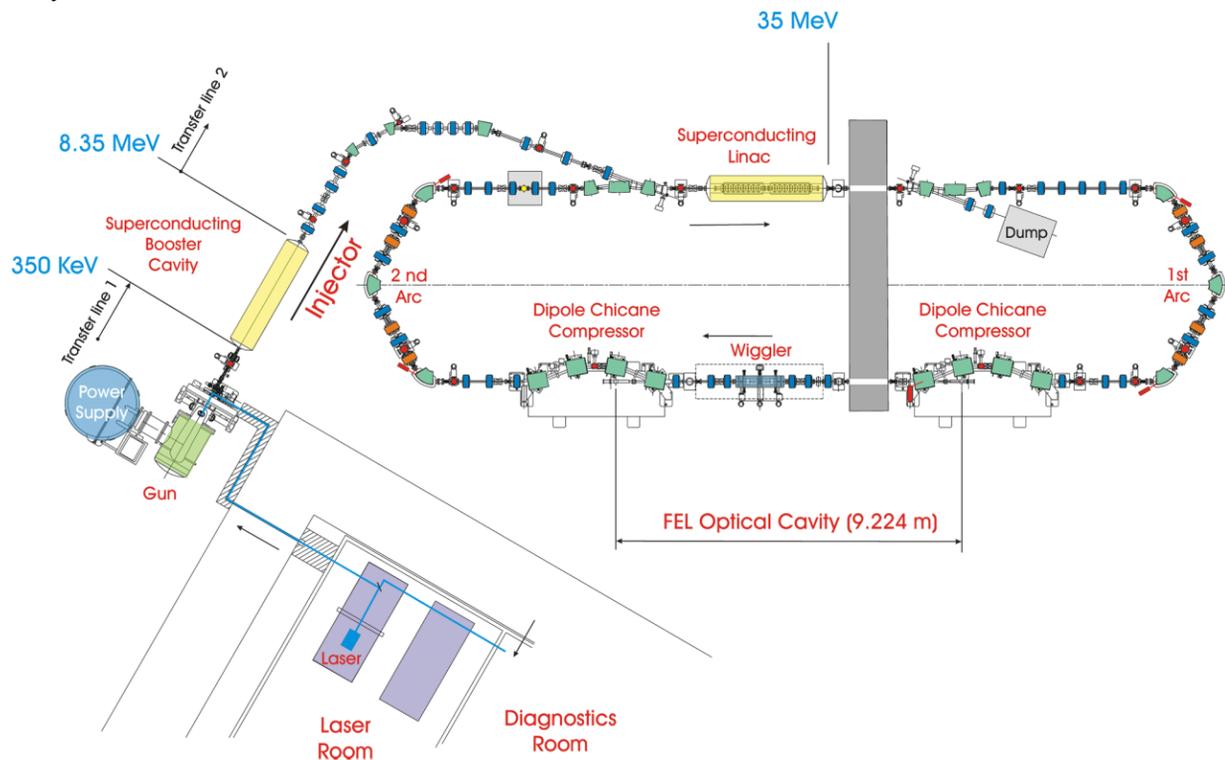


Figure 1: ERLP Layout.

PURPOSE OF MEASUREMENTS

The aim is to commission the gun prior to the construction of the rest of the machine. This will demonstrate that the gun meets its performance specifications and can work reliably, and to investigate the transverse and longitudinal properties of the beam produced. Comparing the measurements with computer simulations will validate the codes used to model this high charge and low energy regime. Due to the strong space charge forces at low beam energies, the injector layout can only be modelled properly with multi-particle tracking codes that include space charge effects, for example ASTRA and Parmela.

In order to make these measurements a dedicated diagnostic beamline has been designed and is currently being procured.

Overall Philosophy

The design of the diagnostic beam line described here has been constrained by the placing of the gun, solenoids and buncher cavity in the positions that are broadly optimum for the electron beam properties required for the ultimate operation of the ERLP. The commissioning of the gun is planned to take place in two phases: in phase one multiple diagnostics are positioned in place of the buncher cavity in order to study the beam parameters at this position, as this is the minimum aperture in the injector. For phase two the diagnostic is removed to make space for the buncher, and moved to make similar measurements at the proposed position of the centre of the first cell of the superconducting booster cavity. There are two advantages to this strategy:

- The disruption required in converting the diagnostic beam line into the ERLP injector is minimised.
- Most of the diagnostics can be left in place during subsequent operation of the ERLP for continued study of the performance of this part of the machine.

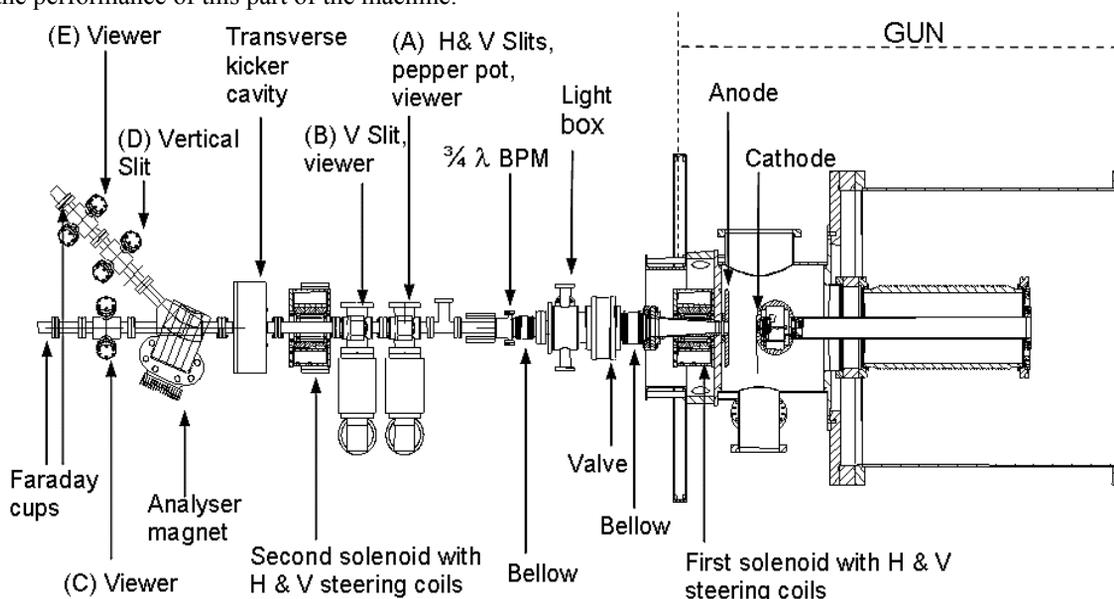


Figure 2: Phase One Diagnostic Layout.

A large-bore solenoid directly follows the gun vacuum chamber, which includes horizontal and vertical steering coils, and a RF-shielded gate valve. Immediately after the valve is the light box, a device that directs incident laser light onto the photocathode and removes light reflected from the wafer into a beam dump. The light box is followed by some bellows and a BPM.

From this point onwards, the configurations for phase one gun commissioning, phase two gun commissioning and ERLP operation are different.

Beam Properties to be Measured

The measurements required to characterise the electron beam from the gun are:

- Electron beam position.
- Total charge in the pulse train.
- Pulse train length and charge stability within train.
- Electron beam energy and energy spread.
- Transverse beam profile.
- The electron beam transverse emittance.
- Longitudinal bunch shape.
- Longitudinal emittance.

Phased Measurements

In phase one of the gun commissioning a screen viewer follows the BPM and replaces the buncher. The layout of the diagnostic beam line at this point is shown in Fig. 2. For phase two, the first slits/pepper pot/viewer unit (A) is removed to make space for the buncher cavity. This diagnostic is then added between the analyser magnet and viewer (C) in the straight-on path to study the beam properties at the envisaged position of the 1st cell of the booster cavity.

DIAGNOSTIC MEASUREMENTS

Electron Beam Position

Phases 1 & 2: The $\frac{3}{4} \lambda$ BPM, all viewers and the Faraday cups can be used to position the electron beam and thread it through the diagnostic beamline. Using BPM readings to provide a cross-check with viewer measurements will improve accuracy.

Total Charge in the Pulse Train

Phases 1 & 2: Faraday cups are used to measure the charge produced for various cathode-laser powers and pulse durations (giving an estimation of quantum efficiency and electron losses).

Pulse Train Length and Charge Stability Within Train

Phase 1 & 2: The $\frac{3}{4} \lambda$ BPM and the Faraday cups can be used to study the stability of the laser and cathode response.

Electron Beam Energy and Energy Spread

Phases 1 & 2: Viewers (B & C) are used for setting up the analyser magnet, as the beam must be centred in the magnet for an accurate measurement. The vertical slit (B), analyser magnet and viewer (E) are used to measure the energy and energy spread.

Electron Beam Size

Phase 1: Viewers (A, B & C) are used to measure the evolution of beam size for comparison with simulation codes, and map the beam size at the location of the buncher for various parameter settings (e.g. beam energy, bunch charge, spot size at the cathode and solenoid field strength).

Phase 2: The same measurements that are taken in phase one are made at the position of the centre of the first cell of the booster.

Electron Beam Transverse Emittance:

Phase 1: Method 1 - The pepper pot and viewer B or method 2 - the slits (A or B) and viewers (B or C respectively) are used to measure the transverse emittance at the position of the buncher and unit B.

Phase 2: The transverse emittance at the position of the centre of the first cell of the booster is measured using the pepper pot and viewer (C).

Longitudinal Bunch Shape

Phases 1 & 2: The transverse kicker cavity and viewer (C) are used to measure the bunch shape dependence on the initial laser pulse length, beam energy, bunch charge (and buncher cavity gradient in phase two).

Longitudinal Emittance

Phases 1 & 2: Combining the results from the electron beam energy, energy spread and the longitudinal bunch shape measurements, the longitudinal emittance can be estimated.

MODELLING

The dimensions of the electron bunch at the cathode are mainly dependent on the laser and cathode material used. With a GaAs cathode, the electron bunch is longer than the laser pulse due to the emission process in this material [3]. The response behaviour of GaAs is difficult to predict and there is limited experimental data available. For modelling the longitudinal profile of the bunch has been assumed to be Gaussian, with an RMS length of 20ps. Transversely a near flat-top profile should be achievable from the laser, and a beam diameter of 4mm (1mm RMS) was used for the model. Table 1 shows a summary of the operating parameters. The evolution of the beam has been modelled for the injector to the end of the superconducting booster cavity [4].

The characteristics of the beam at the central position of the buncher cavity and first accelerating cell are summarised in Table 2.

Table 1: Injector parameters used for ASTRA modelling

Parameter	Unit	
Laser spot size	mm	4
Laser pulse length	ps	20
Bunch charge	pC	80
Gun voltage	kV	350
1 st solenoid	G	300
Buncher	MV/m	1.7
Phase	deg	90
2 nd Solenoid	G	210

Table 2: Summary of ASTRA modelling results

Characteristic	Unit	Buncher Cavity	First Cell
Transverse beam size (RMS)	mm	3.4	1.8
Normalised transverse emittance (RMS)	μm	1.6	3.1
Bunch length (RMS)	mm	6.7	3
Longitudinal emittance (RMS)	keV	3.7	1.7
	mm		

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