THE STATUS OF THE DARESBURY ENERGY RECOVERY LINAC PROTOTYPE (ERLP)

S.L.Smith, STFC Daresbury Laboratory, Warrington, UK.

Abstract

This paper reviews the current status of the Energy Recovery Linac Prototype (ERLP) at Daresbury Laboratory. The ERLP has been constructed as part of an R&D programme to develop an advanced energy recovery linac-based light source (4GLS). The 35 MeV technology demonstrator is based on a combination of a DC photocathode electron gun, a superconducting booster linac and main linac operating in energy recovery mode, driving an IR-FEL.

INTRODUCTION

The ERLP project was funded in April 2003 as part of the more general Exploratory Phase for 4GLS. ERLP is a smaller scale prototype ERL with energy of 35 MeV, designed to assist in addressing the considerable challenges of 4GLS in areas such as beam dynamics, accelerator technology, FEL physics and effective user exploitation.

The priorities for this machine are: to gain experience of operating a photoinjector gun and superconducting linacs; to produce and maintain high-brightness electron beams; to achieve energy recovery from an FEL-disrupted beam and to study challenging synchronisation issues.

It will also incorporate an FEL test facility based on a wiggler magnet previously used in the Jefferson Laboratory IRFEL and supplied on loan as part of an international collaboration. In addition to the IR radiation from the FEL, the facility will produce x-rays by a Compton backscattering source and utilise terahertz radiation from a dipole magnet in the bunch compressor. The linac from ERLP will be used as an injector for EMMA [1], which is a non-scaling Fixed-Field Alternating Gradient (FFAG) technology demonstrator.

The construction and installation of the whole machine (barring a few diagnostic devices currently being used with the gun) has been completed in preparation for beam commissioning later this year.

The layout of the ERLP is illustrated in Fig. 1, while the key parameters are listed in Table 1.

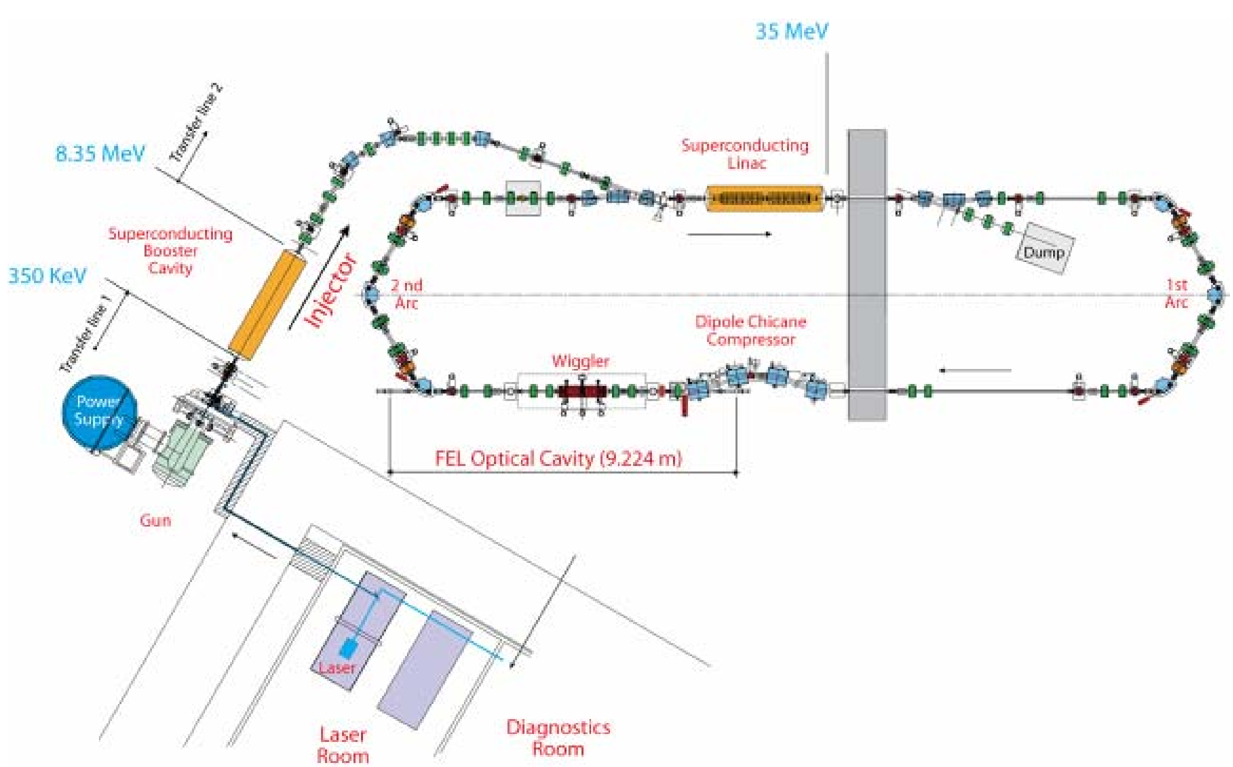

Figure 1: ERLP layout.

Since the status of this project was last reported [2] there have been a number of significant milestones achieved:

- First electrons obtained from the gun;
- Operation of the cryogenic system to cool both superconducting linac modules to 2K;
- Demonstration of RF-photoinjector drive laser synchronisation;
- High power RF tests of the linac module;
- Commissioning of a terawatt laser to drive a Compton backscattering X-ray source and electro-optic longitudinal beam diagnostics.

Table 1: ERLP parameters

Parameters		**Units**
Nominal Gun Energy	350	keV
Injector Energy	8.35	MeV
Circulating Beam Energy	35	MeV
RF Frequency	1.3	GHz
Bunch Repetition Rate	81.25	MHz
Nominal Bunch Charge	80	pC
Maximum Train Length	100	µs
Maximum Train Repetition Rate	20	Hz
Maximum Average Current	13	µA

GUN COMMISSIONING

The gun commissioning has taken place in two phases separated by a period of investigation and remedial action aimed at restoring the high voltage performance of the gun after significant degradation occurred, associated with the process of cathode activation.

In the first phase, the electron gun operated during late July and August ’06. The first electron beam was obtained with the gun injecting into a dedicated gun diagnostic beamline [2], Fig. 2. The beam was detected at 01:08 on Wednesday 16th August with the gun operating at 250 kV. The beam transport was optimised and the basic characteristics of the beam were then ascertained using the diagnostics line. Encouraging results were obtained, however the Gun was unable to support high voltage following cathode re-caesiation at the end of August. It was baked and still exhibited similar breakdown and it was only after the Gun was stripped down and cleaned that high voltage performance was restored.

During the second phase of commissioning, which occurred in the first half of 2007, operating voltages of 350 kV were achieved. The performance was generally limited by field emission to between 350 kV and 250 kV. This period allowed commissioning of the diagnostic line, including the operation of the RF buncher and transverse kicker during which pulses from the photoinjector laser were synchronised with the machine RF using a feedback control system provided by the laser manufacturer. Sub-picosecond timing jitter is routinely achieved and work to reduce this to the 100 fs level is continuing.

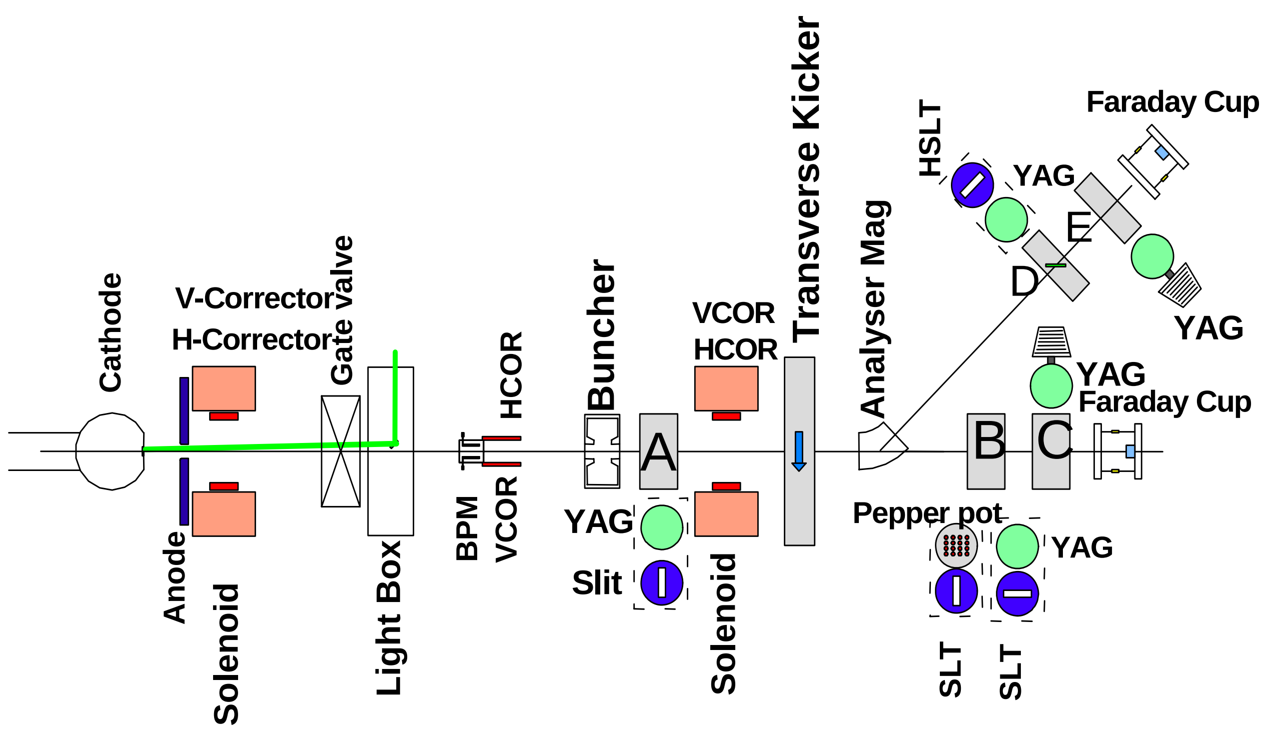

Figure 2: Diagnostics line schematic.

During this second period, the performance of the photoinjector laser and gun combination has been developed to the point where only the measurements at high bunch charge remain. This work has been undertaken in parallel with ex- and in-situ developments of the Negative Electron Affinity (NEA) cathode technology in order to reach Quantum Efficiencies (QEs) of a few percent (along with a workable lifetime) required for the highest bunch charge. Problems encountered have been concentrated in two key areas. Firstly, the photocurrent monitored during cathode activation has been swamped by a significantly larger current derived from caesium ionisation. Secondly, contamination issues following cathode activation have again impaired the ability of the gun to operate at the required voltage and to maintain the XHV conditions required for workable cathode lifetime.

To address these problems a decision was made to change the cathode and bake the gun again. Stroboscopic instrumentation has been tested which now allows the detection of photocurrent during activation by filtering the spurious DC current and other steps are being taken to improve the vacuum performance of the gun and the cathode lifetime. The process of handling the cathode before activation was changed to eliminate test activation before installation. The vacuum criteria for ending the bake will now include an assessment of the partial pressures, rather than being based solely on the base vacuum pressure. Steps have also been taken to increase the uniformity of bake throughout the gun oven. In addition, NF_3 rather than O_2 will now be used during activation of the cathode. At the time of the workshop the Gun was baking at 250 degrees.

A summary of the results achieved so far is shown in Table 2. On completion of the current vacuum bake and high voltage conditioning, the diagnostics line will be used to characterise the beam from the photoinjector at high bunch charge.

Table 2: ERLP commissioning results.

Parameter	**Specification**	**Measured**	**Units**
Beam Energy	350	350	keV
Bunch Charge	80	22	pC
Train Length	100	100	µs
Train Repetition Rate	20	20	Hz
QE (in the gun)	~1	1.5	%
QE (in the laboratory)		3.5	%
RF-laser timing jitter	<1000	650	fs

CONSTRUCTION PROGRESS

As already mentioned, the gun is currently beaming into a dedicated gun diagnostic beamline. This prohibits the placement of the first linac module (the booster) in its final position. Other than this and some diagnostic devices currently being used with the gun, the electron beam transport system is fully assembled and under vacuum. Fig. 3 shows the shielded area with the installed girder modules making up the beam transport system. Installation of photon beam transport systems required for the FEL output, Compton backscattering, electro-optic longitudinal diagnostic laser and terahertz beamline is continuing, as is electrical and controls commissioning.

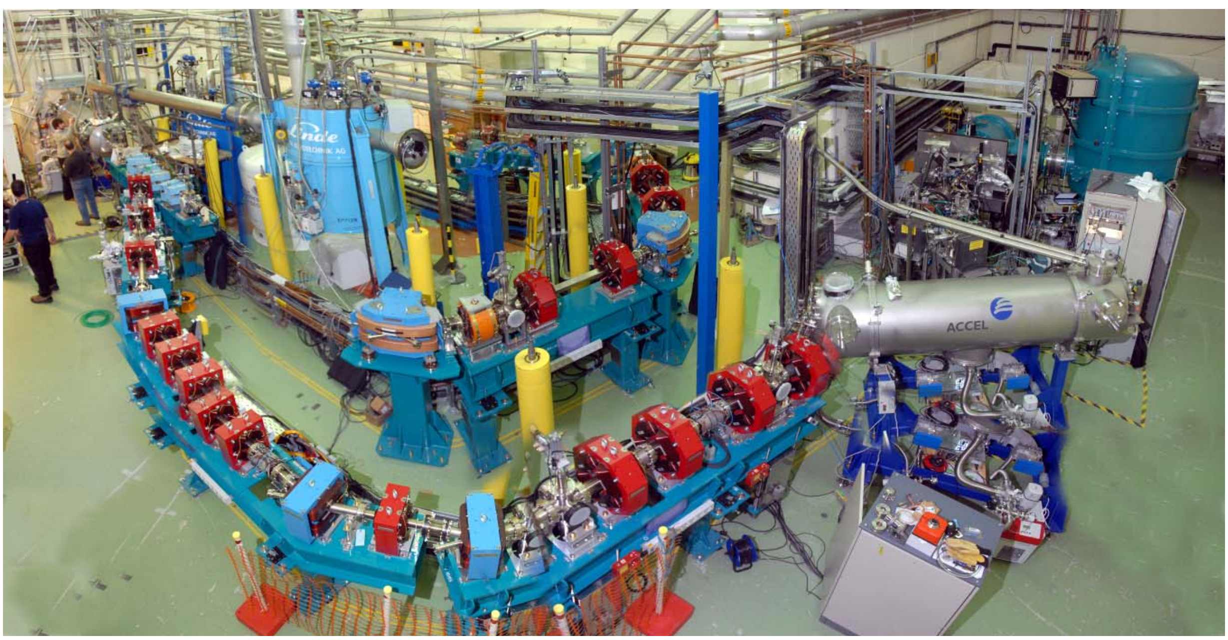

Figure 3: Electron beam transport system

All of the ERLP beam transport system was assembled as individual modules on single girders in an ISO Class 100 clean room. These were then aligned and sealed with dry N_2. Temporary clean conditions were then established in the local work area prior to the joining of these modules to the accelerator. This was undertaken in order to produce exceptionally low levels of particulate contamination inside the vacuum envelope.

CRYOGENIC SYSTEM

Following several months of commissioning work and the identification and rectification of a number of problems, the system finally met its operational specification on 16th May 2007. It is capable of simultaneously cooling both linac modules to 2 K and maintaining this temperature under the dynamic load imposed by high gradient operation of the linac system. Initial tests at 1.8 K indicate that the system should be able to sustain module operation at this lower temperature.

HIGH-POWER RF COMMISSIONING

At the time of this workshop, high-power RF tests have commenced with the main linac module, one of whose cavities has so far reached 12 MV/m (see Fig 4).

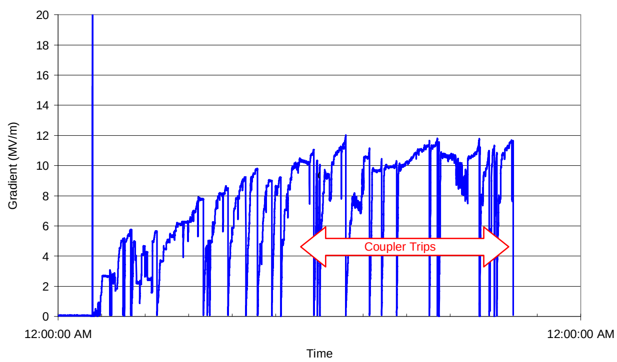

Figure 4: Main linac cavity 1 high-power RF processing.

CW conditioning of the input coupler was clearly observed, resulting in a number of vacuum and arc events at > 10 MV/m. Progress has been ultimately halted however due to a mechanical failure of the tuner mechanism, which is currently being addressed. Once these have been fixed conditioning to higher gradients will continue. In addition, it has been decided to operate the booster linac in its current position, rather than waiting until the gun commissioning has finished. This will allow additional time for gun characterisation, without significantly affecting the overall programme.

TERAWATT LASER

Inverse-Compton backscattering is a means of generating, ultra-short x-ray pulses at a low-energy accelerator. An inverse COmpton BAckscattering x-ray source driven by the multi-10 TW Laser installed at Daresbury (COBALD) is being constructed [4]. Hard x-rays, ranging from 15 keV to 30 keV, depending on the backscattering geometry, will be generated by interaction between the laser pulse and the electron beam. The X-rays created from head-on collisions contain 15×10^6 photons per pulse and 5×10^6 from side-on collisions. A highly accurate timing synchronisation scheme is employed to minimise jitter in the X-rays generated.

A commercial laser system has been purchased and installed in the laser room, alongside the photoinjector laser. This laser has now been commissioned and installation of the photon beam transport system is under way. Fig. 5 shows the two alternative (head-on and side-on) laser paths to interaction with the electron beam, just before the first dipole of the second arc. In addition, this laser will be used for the development of an electro-optic longitudinal diagnostic.

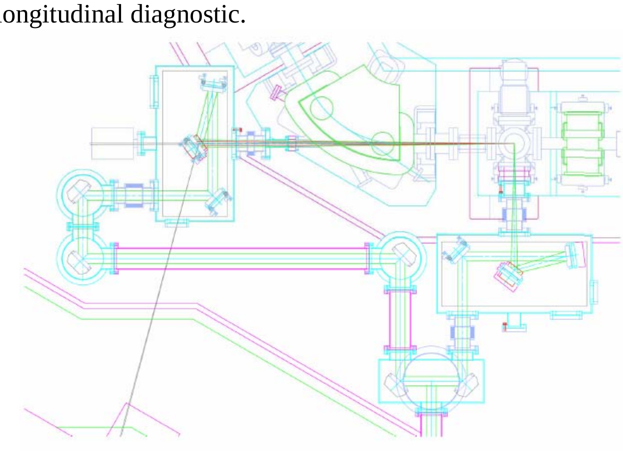

Figure 5: Laser-electron beam interaction region.

CONCLUSIONS

Four years since the conception of a prototype energy recovery project at Daresbury, the installation of the facility is complete and the commissioning of the major technical components is well underway, with completion expected by the end of 2007.

It is hoped that energy recovery will be demonstrated early in 2008, followed by the production of ultra-short x-rays from COBALD, high intensity terahertz radiation from the short electron bunches and infra-red radiation from the free electron laser. Once fully operational, ERLP will be one of the few true electron beam test facilities available in the world. It will be used for development of photoinjector guns, diagnostics, superconducting linacs, synchronisation and for benchmarking codes.

ACKNOWLEDGEMENT

The results presented here represents the work of the whole ERLP/4GLS team and the author would like to acknowledge in particular information obtained for this report from the following colleagues N.Bliss, A.R.Goulden, P.A.McIntosh, D J.Holder and G.Priebe.

REFERENCES

[1] R.Edgecock et al, “EMMA - The World's First Non-Scaling FFAG”, these proceedings.

[2] E.A.Seddon et al, “The Status of the Daresbury Energy Recovery Prototype Project”, EPAC’06, Edinburgh, June 2007, p. 249.

[3] D.J.Holder et al, "ERLP Gun Commissioning Beamline Design", LINAC’04, Lübeck, August 2004, p. 93.

[4] G.Priebe et al, “Inverse Compton Backscattering Source Driven by the Multi-10 TW Laser Installed at Daresbury”, to be published in the proceedings of SPIE Optics + Photonics, San Diego, August 2007.