# MAGNET SPECIFICATION FOR THE DARESBURY LABORATORY ERL PROTOTYPE

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*Abstract*

Daresbury Laboratory has funding for the design and construction of an Energy Recovery Linac (ERL) prototype, to facilitate the research and development necessary for the 4th Generation Light Source (4GLS). In the prototype a 35MeV electron beam will be used to drive an infra-red oscillator free-electron laser (FEL). A number of pre-existing magnets are being used in the layout, so new magnets are being procured, ensuring compatibility with the existing units. This paper gives an overview of the magnet requirements for the facility and details of the engineering realisation and procurement strategy.

## INTRODUCTION

An Energy Recovery Linac Prototype is currently funded and under construction at Daresbury Laboratory. This proof-of-concept facility will enable the R&D necessary for the 4th Generation Light Source (4GLS), a novel high intensity source. A more detailed overview of the project status is given elsewhere [1].

## LAYOUT OF ERLP

The layout of the ERLP is shown in Figure 1 and is summarised as follows:

- a photocathode gun produces electrons at about 350keV;
- a superconducting booster cavity accelerates the beam to 8.35MeV;
- a fairly long injection line transports the beam through an isochronous dog-leg into the injection chicane;
- a superconducting linac accelerates the beam to 35MeV;
- a $180^\circ$ triple-bend achromat (TBA) arc [2] transports the beam isochronously to the back straight;
- a 4-dipole chicane (buncher) compresses the bunches to give the high peak current necessary for FEL operation;
- a planar wiggler, supplied on loan from Jefferson Laboratory, is used for the FEL, which is predicted to induce a full energy spread in the beam of up to 4%; [3]
- a 4-dipole chicane (debuncher) decompresses the bunches;
- a $180^\circ$ TBA, identical in design to the outward arc, transports the disrupted beam back to the injection straight;
- the linac recovers most of the energy in the beam by decelerating back to 8.35MeV;
- a 3-dipole extraction chicane steers the decelerated beam to a dump line.

## MAGNET REQUIREMENTS

The requirements for the dipoles and quadrupoles are summarised in Tables 1 and 2. The parameters have been derived through extensive simulations using the particle tracking code ASTRA for the gun to the end of the booster, then MAD8 for the subsequent beam transport system through to the dump. More details are reported elsewhere [4, 5].

Daresbury Laboratory has kindly been offered on loan a number of magnets from Jefferson Laboratory which will be included in the layout—the final column of Tables 1 and 2 indicate whether each magnet type is to be a new design (to be procured) or a magnet on loan.

### *Dipoles*

It can be seen that the required field strengths for all these dipoles are low. Modelling and coarse optimisation in Opera 2D indicate that the field strengths and qualities can easily and practicably be achieved with a coil current density of around $1\mathrm{A/mm}^2$ for all dipole types. The exception to this is the arc dipoles (Type DD) which will require a higher current density of about $3\mathrm{A/mm}^2$. This means that the arc dipoles are expected to be water-cooled whereas all the other dipole types will be specified as air-cooled.

The dipole gaps are derived from simulations in MAD8 and beam aperture predictions. The gaps are mostly set at 54mm. The main exception is in the injector dipoles where uncertainties in the predicted output from the photoinjector motivate a larger aperture of 71mm.

Dipole Type DF is a new magnet needed to match the performance of magnet Type DE on loan from Jefferson Laboratory. Similarly, Type DG is a new magnet to match Type DB, and Type DH will match Type DC.

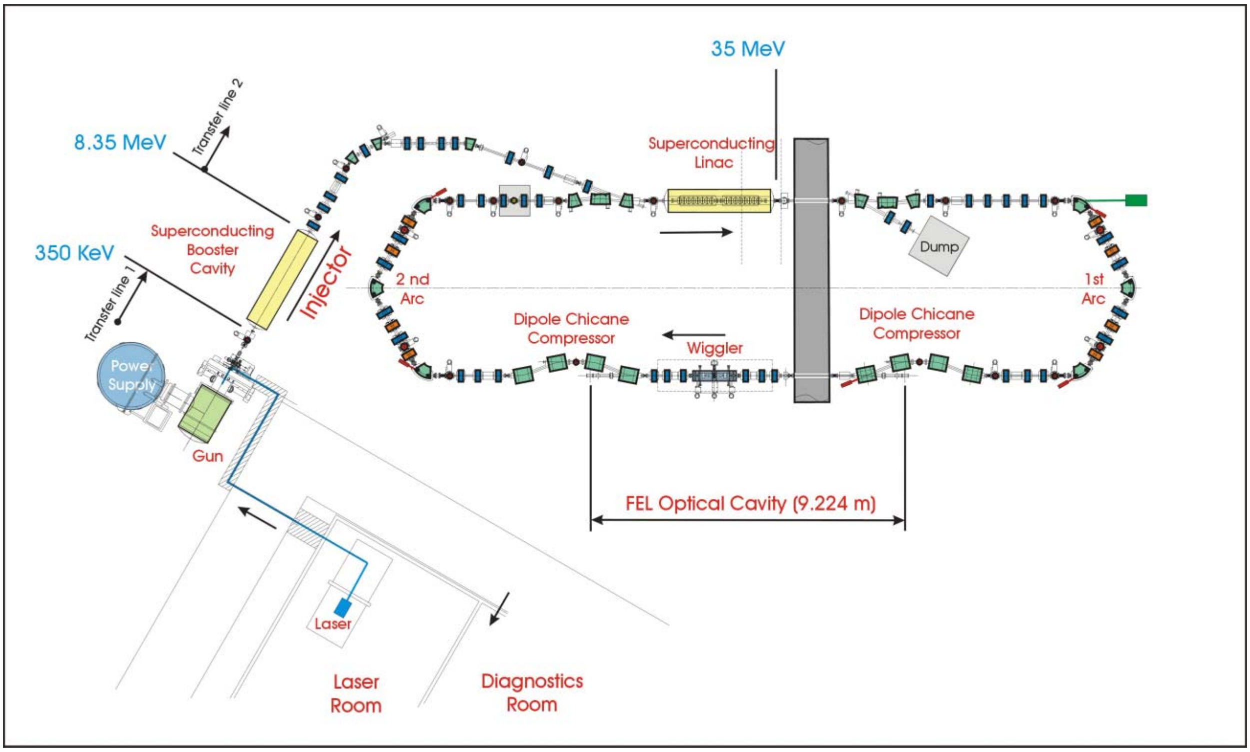


Figure 1: The layout of the ERL Prototype.

Table 1: Summary of Dipole Specifications

| Type | Location | Length | Strength | Quality | H. Good Field | Bend Angle | Gap | Quantity | Status |
|---|---|---|---|---|---|---|---|---|---|
| | | m | T | $\frac{\Delta B_y(x)}{B_y(0)}$ | mm | $\circ$ | mm | | |
| DA | Injector | 0.200 | 0.08 | $10^{-4}$ | $\pm 33$ | 30 | 71 | 2 | New |
| DF | Debuncher | 0.410 | 0.11 | $10^{-4}$ | $\pm 35$ | 20 | 54 | 2 | New |
| DE | Buncher/Debuncher | 0.410 | 0.11 | $10^{-4}$ | $\pm 35$ | 20 | 54 | 6 | Loan |
| DG | Injector | 0.215 | 0.05 | $10^{-4}$ | $\pm 35$ | 20 | 54 | 1 | New |
| DB | Inj/Ext Chicane, outer | 0.215 | 0.05 | $10^{-4}$ | $\pm 35$ | 4.74 | 54 | 4 | Loan |
| DH | Inj chicane, inner | 0.430 | 0.05 | $10^{-4}$ | $\pm 35$ | 9.49 | 54 | 1 | New |
| DC | Ext chicane, inner | 0.430 | 0.05 | $10^{-4}$ | $\pm 35$ | 9.49 | 54 | 1 | Loan |
| DD | TBA Arcs | 0.500 | 0.27 | $10^{-4}$ | $\pm 40$ | 60 | 50 | 6 | New |

### *Quadrupoles*

The field gradient requirements are relatively low, again indicating that air-cooled designs with coil current densities of approximately $1\mathrm{A/mm}^2$ will be appropriate. The Type QD quadrupoles, which are placed immediately after the booster and in the TBA arc, need a large aperture—simulations indicate that this is necessary to allow matching to varying Twiss parameters from the exit of the booster.

For reasons of economy the specified aperture was further increased to a value of 90mm, which corresponds to the design of the arc quadrupoles which have the same magnetic length and a similar gradient requirement. This allows the Type QD quadrupole design to be used both in the injector and in the TBA arcs.

The return arc must transport a beam with a large FEL-induced full energy spread (up to 4%). The aperture requirement is the sum of the beam size and the trajectory error, given by

$$A_x = n_\sigma \sqrt{\beta_x \epsilon_x} + \eta_x \sigma_p + \delta_x \qquad (1)$$

where $n_\sigma$ is the adopted number of beam sigmas, $\beta_x$ the horizontal Twiss parameter, $\epsilon_x$ the horizontal emittance, $\eta_x$ the dispersion, $\sigma_p$ the relative energy spread and $\delta_x$ the trajectory error. The combination of dispersion and energy spread therefore dictates a large horizontal aperture in the arc. For economy, and to allow as much flexibility as possible to explore different tunings in this prototype machine, the outward and return arcs are identical.

The largest apertures are in the Type QE quadrupoles, which are found in the beam dump—here the large relative energy spread induced by the FEL has been magnified by the deceleration in the linac and can be more

Table 2: Summary of Quadrupole Specifications

| Type | Location | Length | Gradient | Quality | Good Field | Inscribed Diameter | Quantity | Status |
|---|---|---|---|---|---|---|---|---|
| | | m | T/m | $\frac{\Delta G(x)}{G(0)}$ | mm | mm | | |
| QA | Injector | 0.150 | 1.1 | $10^{-3}$ | $\pm 33$ | 71 | 8 | New |
| QB | Straights | 0.150 | 2.75 | $10^{-3}$ | $\pm 25$ | 54 | 13 | Loan |
| QC | Straights | 0.150 | 2.75 | $10^{-3}$ | $\pm 25$ | 54 | 6 | New |
| QD | Injector and TBA | 0.150 | 1.82 | $10^{-3}$ | $\pm 40$ | 90 | 12 | New |
| QE | Dump | 0.150 | 1.1 | $10^{-2}$ | $\pm 120$ | 247 | 3 | New |
| QF | FEL | 0.150 | 2.8 | $10^{-3}$ | $\pm 25$ | 54 | 4 | Loan |

than 10%. This energy spread, combined with the dispersion produced by the extraction bend, dictate an aperture of 247mm. However, the field gradient quality required here is only $\Delta G(x)/G(0) = 10^{-2}$ which is less stringent than the $10^{-3}$ specified elsewhere. This lower gradient quality will allow the physical dimensions of the Type QE quadrupoles to be limited somewhat .

The Type QC quadrupoles used in the straights are new magnets to match the performance of the Type QB magnets on loan from Jefferson Laboratory.

### *Sextupoles and Correctors*

Sextupoles are required in the arcs for optimising the bunch compression for off-momentum particles [2]. The parameters are not yet fully determined. Combined function correctors (horizontal and vertical correction) are to be used as well as correctors within the arc dipoles with maximum kick around 10mrad.

## MAGNET PROCUREMENT

### *Specification*

Preliminary magnet design work and optimisation has been done at Daresbury Laboratory. The finite element code Opera 2D has been used to assess the feasibility of the required specifications and allow a realistic estimate of all physical dimensions and power supply requirements. This will enable the number of power supply types to be minimised and allow commonality wherever possible between the new magnets and loaned magnets.

The procurement strategy is to produce a performance based specification. Manufacturers will be asked to produce their own designs to give the required field specifications, meeting the stated excitation parameters and dimensions. Magnets will be accepted on the basis of magnetic measurement together with electrical and thermal tests.

As all the dipoles will operate with low magnetic fields in poles and yoke, high saturation flux density, low carbon steel will be unsuitable. This material has high coercivity and therefore can result in varying residual fields in the different dipole magnets. To avoid the need for repeated degaussing, the specification will place limits on the residual field present in the dipoles after excitation to full flux density. Wherever possible low coercivity silicon steel laminations will be used for the magnet yokes.

## ACKNOWLEDGEMENTS

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## REFERENCES

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