LATTICE DESIGN FOR THE FOURTH GENERATION LIGHT SOURCE AT DARESBURY LABORATORY

M.A. Bowler, B.D. Muratori, H.L. Owen*, S.L. Smith,
ASTeC, Daresbury Laboratory, Warrington, UK
S.V. Miginsky, BINP, Novosibirsk, Russia

Abstract

The proposed Fourth Generation Light Source (4GLS) has three electron transport paths: an energy recovery loop containing the main linac, IDs and a VUV-FEL, a separate branch after the main linac for an XUV-FEL and a transport path for an IR-FEL. The first two present major challenges in lattice design. The energy recovery loop will be fed by a high average current gun, with bunches of charge of about 80 pC. High charge (1 nC) bunches from a high brightness gun will be accelerated prior to the main linac and split into the XUV-FEL branch using energy separation after the main linac. We present a lattice design and results from numerical modelling of the electron bunch transport. The requirements of the machine are short bunches, a small emittance for both branches and an overall topology which gives a reasonable dimension for the building. Different transport and compression schemes were assessed to meet these requirements whilst balancing the disruptive effects of longitudinal and transverse space charge, CSR, wakefields and BBU. Investigations into all of these instabilities are summarised together with other transport issues and the resulting requirements on all IDs.

A FOURTH-GENERATION LIGHT SOURCE IN THE UK

Daresbury Laboratory is proposing to construct a fourth-generation light source facility - 4GLS - delivering both free-electron laser and spontaneous synchrotron radiation output, with short photon pulses in the femtosecond regime so that, for example, novel pump-probe experiments may be carried out. A conceptual design report has recently been produced [1, 2], and the scientific motivations for the project are described elsewhere [3].

4GLS consists of three inter-related accelerator systems. The first channel is a high-average-current loop (HACL) delivering 100 mA of current with a small transverse emittance and short bunch length (<1 ps) via a quasi-continuous bunch train from a 1.3 GHz frequency injector. The large beam power (60 MW at 600 MeV) necessitates the use of energy recovery, by returning the electron bunches for deceleration in the same linac used for acceleration, after their passage through the spontaneous devices and VUV-FEL [5]. An energy recovery linac (ERL) prototype accelerator is presently being commissioned at Daresbury Laboratory that will explore this and other issues [6]. VUV-FEL operation with bunch repetition rates above $\sim$4.33 MHz is not presently feasible due to mirror power limitations, so a lower bunch repetition rate will be provided in the HACL for this mode. This channel of the accelerator transport is shown schematically in Figure 1.

The second accelerator system is a single-pass channel providing 1 nC bunches with a peak current $\simeq 1.5$ kA to an XUV-FEL seeded by a high-harmonic generation (HHG) laser [7]. A common linac providing ~ 600 MV acceleration is used for both the HACL and XUV channels for economic reasons; this linac will consist of 6 cryomodules each comprising nine 7-cell TESLA-type cavities [4]. A schematic of the XUV-FEL channel is given in Figure 2. The average power carried by the XUV-FEL beam is relatively modest at 1 kW, so after a spent-beam undulator these bunches are delivered to a beam dump. The final accelerator system consists of a SC linac-based injector [8] delivering bunches from 1 to 10 ps length to one of two cavity-based IR-FELs [2]. The beam transport to each cavity device is similar, and uses the single stage of linac acceleration to provide a variable energy chirp to the electron beam, followed by bunch compression in a 4-dipole chicane. A summary of the 4GLS parameters is given in Table 1.

COMBINED BEAM TRANSPORT AND COMPRESSION

The use of a common linac for the HACL and XUV branch introduces some complexity into the compression design. Also, whilst the XUV branch must deliver a short, high-peak-current bunch in only one location (at the FEL), the HACL must deliver short bunch lengths <1 ps to six insertion device (ID) straights, the last of which contains the VUV-FEL. To avoid interference of the XUV bunches with the HACL bunches, a novel scheme is proposed which accelerates the XUV and HACL bunches with opposite signs in off-crest phases; this gives a number of advantages. Firstly, since the two bunch types (of different energies and charges) are not accelerated contemporaneously, there is no space charge effect of one bunch on the other; separating the bunches by ~ 40 ps (around 18 degrees) is also sufficient to reduce the longitudinal cavity wakefield kick [9] from the XUV bunch onto the HACL bunch to an acceptably small amount (50 kV), and means that a bunch does not have to be omitted from the HACL train.

* h.owen@dl.ac.uk

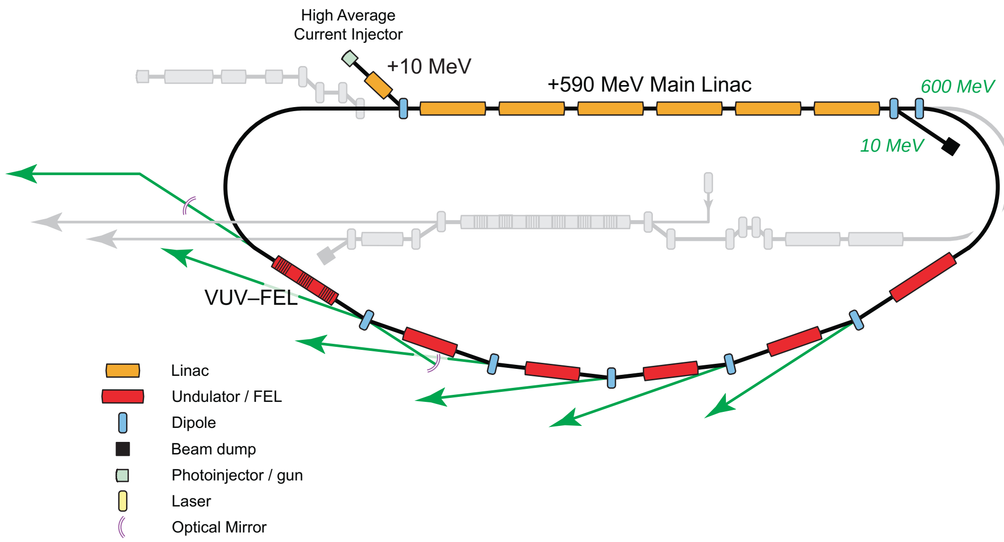

Figure 1: The high-average-current loop of 4GLS, showing the energy recovery transport channel and the disposition of the VUV-FEL.

Table 1: 4GLS Accelerator Parameters

	XUV-FEL	100 mA	VUV-FEL	IR-FEL
Energy	750-950 MeV	600 MeV		25-60 MeV
Bunch Rate	1 kHz	1.3 GHz	4.33 MHz	13 MHz
Bunch Charge	1 nC	77 pC		200 pC
$\varepsilon_{n(x,y)}$	2 mm-mrad			10 mm-mrad
σ_E (proj.)	0.1 %			0.1% (60 MeV)
σ_l (r.m.s.)	< 250 fs	100-900 fs	100 fs	1-10 ps
Beam Power	1 kW	60 MW	200 kW	156 kW (60 MeV)

XUV Channel Transport

The XUV bunch transport is conventional in that a two-stage compression scheme is used, the two bunch compressors being chicane-like (for which we use the sign convention that R_{56} is positive). The first bunch compressor at 160 MeV is unusual in that it must also serve as a merge with the returning 600 MeV HACL beam; this is achieved by using a combination of a 4-dipole slide for the XUV bunches ($R_{56} = 113$ mm) with a 4-dipole chicane for the HACL return beam, the last dipole being common to both beams. A third-harmonic system giving 30 MV deceleration is proposed to perform linearisation of the main RF curvature. After the common linac the 1 kHz, 750 MeV XUV bunches must be separated from the 1.3 GHz, 600 MeV HACL bunches, a regime where kickers or RF deflectors are unfeasible. A magnetic spectrometer is therefore proposed, after which the two branches are deflected in opposite directions by two dipoles before entering into their respective arcs; the R_{56} in each branch is around 100 mm. The alternative scheme of a slide/chicane combination cannot be used here as the XUV bunches would be over-compressed leading to unacceptable coherent synchrotron radiation emission. To minimise the CSR emission the spectrometer bends inwards leaving the higher energy XUV channel outside the HACL channel. To pass the XUV channel within and under the HACL channel a solenoid is used to rotate the principal beam axes by 2 degrees. The XUV bunches then pass through an arc tilted by the same amount to bring them ~ 60 cm under the HACL channel; a second solenoid rotates the principal axes back to the plane of the facility. The XUV arc compensates the part-compression from the beam separator; after this the beam passes through a booster linac which gives energy tuning for the XUV-FEL from 750 to 950 MeV, a second chicane bunch compressor, a FODO diagnostic section [2], and a final dog-leg which provides both energy collimation and an entry point for the HHG seed laser. An undulator which utilises the spent electron bunches from the XUV-FEL gives a spontaneous source with intrinsically good synchronisation with the FEL.

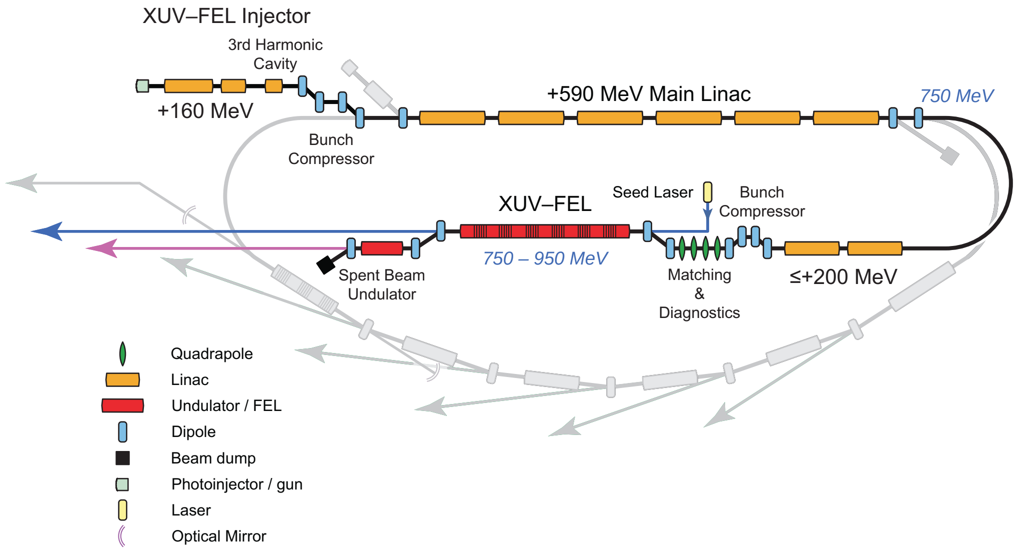

Figure 2: The XUV-FEL branch of 4GLS, showing the XUV-FEL and spent-beam undulator which are driven in this channel.

HACL Channel Transport

The HACL channel transports lower charge bunches of 80 pC, and so the longitudinal cavity wakefield is lower, reducing the induced energy spread and meaning that it is possible to accelerate these bunches on the opposing RF slope to the XUV bunches (see above). The bunch separator now acts as a decompressor, and the following arcs as compressors. The first is a 150 degree FODO arc with adjustable (negative, or arc-like) R_{56}, in which it is proposed to perform emittance diagnostics and collimation of the beam halo generated upstream [2]. Six dispersion-free ID straights are separated by five triple-bend achromats each bending 12 degrees which allow for a small and adjustable negative R_{56} to give the final compression. A balance will be made between the bunch lengths provided in each straight with the disruption from resistive-wall wakefields the generate in the many tens of metres of small-gap IDs; this is to be determined by future work.

The return 150 degree FODO arc over-compresses the bunches, and is followed by a large chicane-type compressor to return the HACL bunch with the correct chirp orientation for efficient energy recovery upon deceleration. This return section will also contain an optics section to optimise the beam break-up current threshold [10]. After deceleration a weak 4-dipole chicane is used to divert the decelerated HACL bunches into a 1 MW dump line. The low beam energy of 10 MeV cannot be distributed longitudinally [11], and so beam expansion or raster scanning must be used to increase the beam size to approximately 1 m in size to spread the heat load transversely.

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