INJECTION SYSTEM OF 4GLS LIGHT SOURCE

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Abstract

A description will be given of the injection system designed for the 4th Generation Light Source (4GLS) which is under development at STFC Daresbury laboratory. 4GLS comprises three branches: 750 MeV XUV free electron laser (FEL), an Energy Recovery Linac based 550 MeV High Average Current Loop, which includes VUV FEL and undulator based spontaneous light sources, and Infra Red FEL which operates with electron energy in the range of 25–60 MeV. Each branch has very strict requirements for the beam quality and, as a result, for their electron sources, which are often on the brink (or even beyond) state of the art. This makes the injection system a very complicated part of the machine.

4GLS LIGHT SOURCE

The 4GLS facility is an accelerator based 4th generation high brightness light source. The general layout of 4GLS is shown in Figure 1. It is built on the basis of three interrelated accelerator branches driving a variety of undulator based spontaneous light sources and free-electron lasers. A conceptual design report has been published [1] and work is currently under way for a technical design report due in 2008.

Three separate injectors are required. A grid-modulated thermionic gun will feed the 25-60 MeV IR-FEL branch, a 1.5-cell normal conducting RF gun will feed the 750 MeV XUV-FEL branch and a DC photoinjector will feed the 550 MeV High Average Current Loop (HACL). The required parameters of the 4GLS injectors are summarised in Table 1.

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Table 1. Parameters of the 4GLS injectors

	XUV-FEL	HACL	IR-FEL
Type of the gun	NC RF photocathode	DC photocathode	Grid modulated thermionic
Cathode	Cs_2Te	GaAs	LB_6
Bunch charge, nC	1.0	0.077	0.2
Bunch repetition rate, MHz	0.001	n·4.33/1300	13
Average beam current, mA	0.001	100	2.6
Beam energy, MeV	210	10	25-60
RMS transverse emittance, π·mm·mrad	<2.0	<2.0	<10.0
Laser wavelength, nm	262	520	n/a

XUV-FEL INJECTOR

The XUV-FEL branch comprises a Cs_2Te photocathode based normal conducting RF gun which delivers electron bunches with a charge of 1 nC at a repetition rate of 1 kHz. The bunches, accelerated in the gun to an energy of about 4 MeV, are injected into a two module superconducting linear accelerator where their energy is increased to 210 MeV. Each accelerating module comprises eight 7-cell accelerating sections for which RF amplitude and phases may be set independently. Design of the accelerating modules is identical for the whole machine (see below). The accelerated beam is then directed into

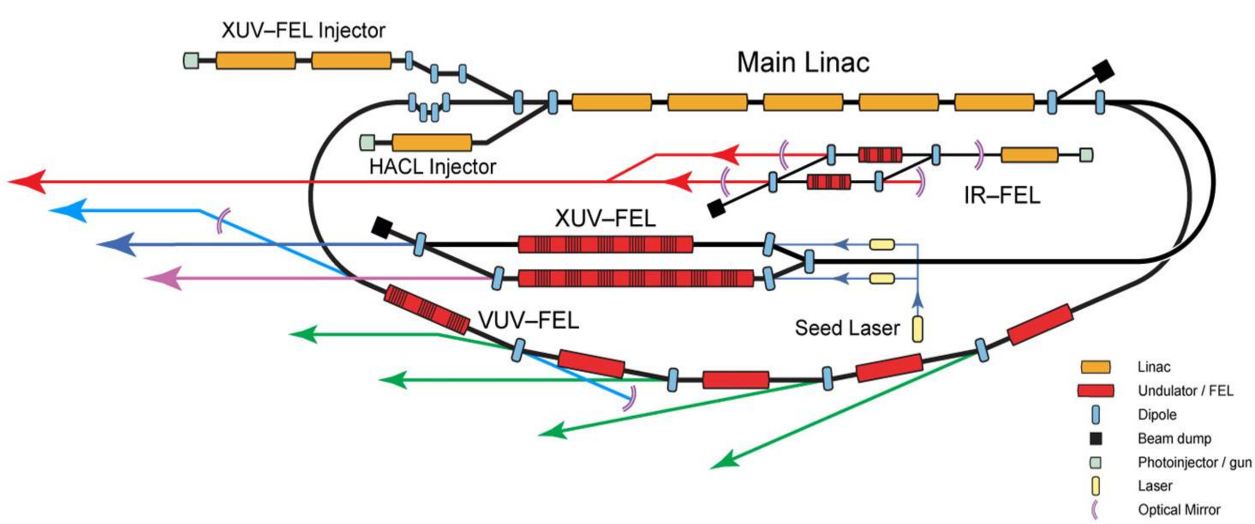

Figure 1: General layout of 4GLS.

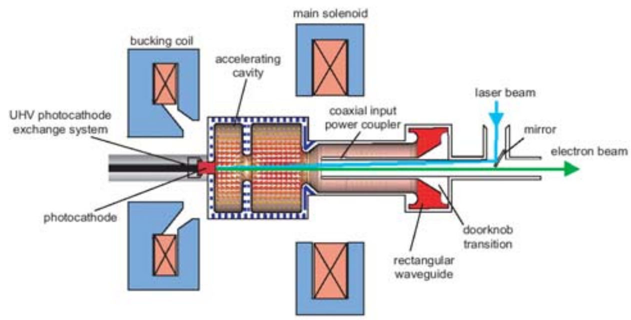

Figure 2. Schematic view of a 1.5-cell normal conducting RF gun.

the main linac by means of a merging section based on a "dog leg" scheme. The phase of acceleration is set off crest in order to provide the bunches with an energy modulation which allows for additional longitudinal bunch compression in the merger. In the 5-module superconducting main linac the beam is accelerated to 750 MeV, deflected by 180º with an isochronous arc and injected into one of two undulators selected by a DC switch yard magnet. The spent beam is deflected into the beam dump.

The design of the gun is similar to the one developed at PITZ (DESY-Zeuthen) [2]. It comprises a 1.5-cell L-band RF cavity which will be fed by a 10 MW pulsed multi-beam klystron through a coaxial coupler integrated with a doorknob transformer. The RF network is based on SF_6 filled rectangular waveguides. The gun will operate at maximum field strength of 40 MV/m. Stability of the RF amplitude at 10^{-3} and phase at 0.1° will be provided by a fast digital feedback in combination with a highly efficient temperature stabilization system. The repetition rate of the RF is 1 kHz. Duration of the RF pulse is selected at a level of 20 µs to provide enough time for stabilisation and restricted from one side by the speed of the feedback and from the other by the maximum average power of the klystron.

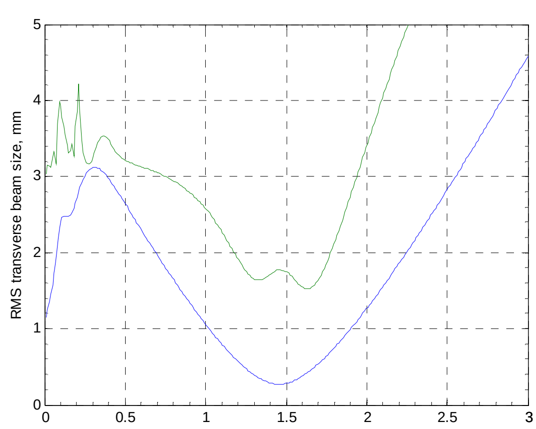

Figure 3. RMS transverse beam size (blue) and rms transverse emittance (green, same units) in the normal conducting RF gun as calculated with the ASTRA code.

Beam focusing and emittance compensation is provided with a main focusing solenoid. Compensation of the magnetic field in the cathode plane is achieved by a bucking coil (Figure 2). The position of the main solenoid is chosen to provide a magnetic field maximum 300 mm from the photocathode. This position allows for obtaining an emittance minimum at the entrance of the linear accelerator, a distance of 1.6 m from the photocathode. Figure 3 shows the results of a beam dynamics calculation made with the ASTRA [3] code for a beam with an initial radius of 2 mm (corresponding to the rms beam size of 1mm on the figure).

HACL INJECTOR

The HACL branch of 4GLS is a single pass energy recovery system which aims to deliver an electron beam of 550 MeV with an average current of up to 100 mA through five insertion device straights, the last of which contains a VUV-FEL undulator. The average current of 100 mA is reached by filling every 1.3 GHz RF bucket with a bunch of charge 77 pC. The beam is accelerated by a superconducting linac which is shared with the beam of the XUV-FEL branch.

The HACL injector needs to provide a beam of 10 MeV and of high quality for the insertion devices. These require a normalised emittance of less than 2 π·mm·mrad and an uncorrelated energy spread of less than 0.1 %. The injector also needs to provide a bunch length of less than 3 ps in order for the compression system to achieve the required 100 fs at the entrance of VUV-FEL whilst using sextupoles for linearization [4].

Injector Layout

In order to provide the required beam time structure the injector is based on a GaAs DC photocathode gun, followed by a single-cell buncher cavity based on the Cornell design [5] and two 5 MeV superconducting booster sections [6]. These sections each contain five two-cell cavities which have independently adjustable phases and gradients. A solenoid is placed either side of the buncher cavity to provide transverse beam focusing. Figure 4 shows a schematic layout of the injector.

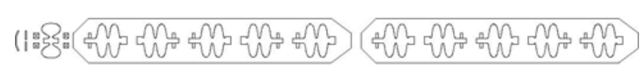

Figure 4. HACL injector layout

Electron Gun

A DC photocathode gun will operate at 500 kV with a GaAs photocathode activated to the negative electron affinity state. This will be back-illuminated by a laser providing a 1.3 GHz train of pulses synchronised to the linac RF.

The main limiting factor of the gun performance is the operational lifetime of the photocathode which is restricted by the back ion stream. Residual gas becomes ionized by the primary electron beam and then acceler-

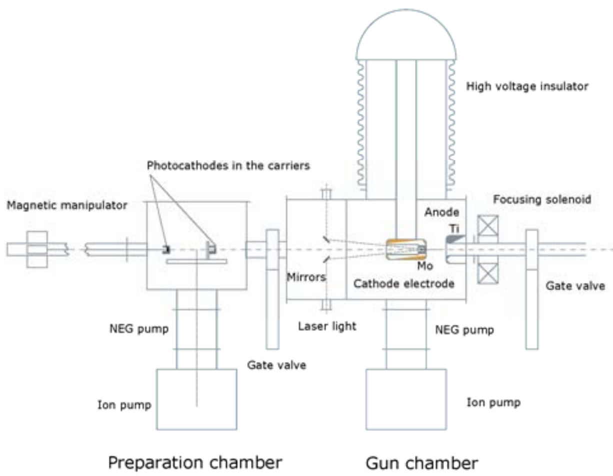

Figure 5. Sketch of the DC photocathode gun.

ated towards the photocathode surface, degrading it, resulting in a decrease in the quantum efficiency (Qe). An extremely high level of vacuum is required to limit this damage. The photocathode lifetime is expected to be around 24 hours and so to minimise downtime between cathode changes, the gun is equipped with a multiple chamber cathode preparation facility as shown in Figure 5. The photocathode will be installed in the gun using a load-lock system from a preparation chamber. This chamber can hold up to 5 photocathodes and includes facilities for heat treatment and activation of the photocathodes with Cs and O_2 or NF_3. In addition it is proposed to have a dedicated hydrogen cleaning chamber to repair degraded photocathodes. Before loading into the gun system, new photocathodes will be chemically cleaned in a nitrogen filled glove box.

Simulations

ASTRA was used to perform beam dynamic simulations from the cathode up to the exit of the second SRF booster. The on-axis field distribution of the electron gun was calculated with POISSON. The beam on the cathode was modelled transversely with a 6 mm diameter "top-hat" profile and longitudinally with a 20 ps rms Gaussian. An initial energy spread of 200 meV was included that gives a thermal emittance of 0.94 π·mm·mrad. Figure 6 shows the evolution of the beam parameters along the injection line and Table 2 summarises them at the exit of the injector. As can be seen, the emittance is larger than required although the slice emittance remains below 2 π·mm·mrad for the majority of the bunch apart from a chirp at the tail.

Table 2. Final beam parameters after 12 m

Transverse emittance	2.8 π·mm·mrad
Bunch length	2.2 ps
Energy spread	0.2 %
Longitudinal emittance	11 π·keV·mm
Energy	10.5 MeV

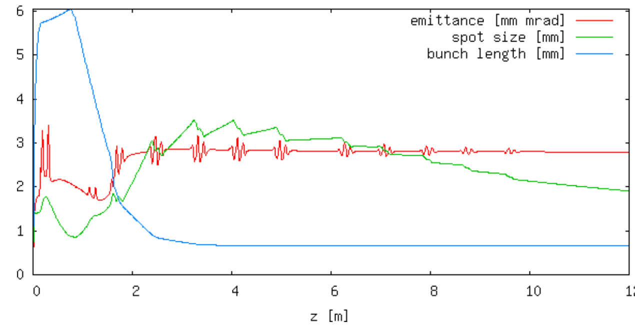

Figure 6. Evolution of the rms values of the normalised transverse emittance, transverse spot size and bunch length along the HACL injection line.

IR-FEL INJECTOR

Figure 7. Industrial grid modulated LB_6 thermionic cathode.

The IR-FEL branch is realised on a classical scheme. The beam is emitted by a 400 kV thermionic gun equipped with an industrial grid modulated LaB_6 cathode (Figure 7) which is able to provide a current of up to 3 A. These types of electron sources have been successfully used on many IR FELs for years. A modulating voltage opens the gun on 67 ps with a repetition rate of 13 MHz synchronous with a 1.3 GHz linac. An emitted bunch of charge 200 pC is accelerated to an energy of 400 keV and travels through a focusing solenoid to the entrance of a sub-harmonic pre-buncher where it is preliminarily compressed. A second solenoid installed after the pre-buncher focuses the beam at the entrance of a linear accelerator. The IR-FEL linac consists of an accelerating module identical to the one used in the main 4GLS linac. Its first section acts as buncher-accelerater and further compresses the beam. Both prebuncher and first accelerating section allow for compressing the bunches to a length of 1-10 ps as required by experiments. Beam energy at the exit of the linac may be set in the range of 20-50 MeV depending on the required wavelength. Major beam parameters at the exit of the linac have been calculated with the ASTRA code and are shown in Figure 8.

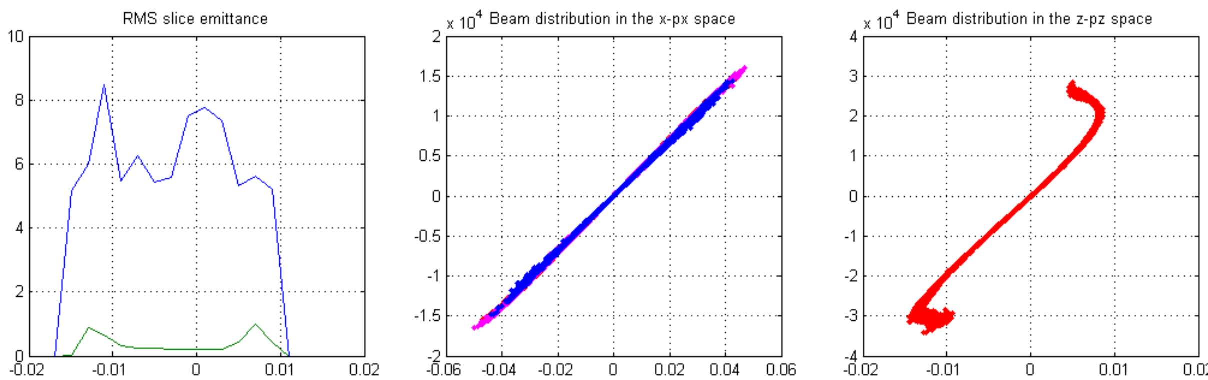

Figure 8. Transverse rms slice emittance (left panel), projected transverse emittance (central panel) and longitudinal emittance (right panel) at the exit of the IR-FEL injector as calculated with the ASTRA code.

CONCLUSION

Of the injectors required for 4GLS, only the thermionic injector for the IR has an analogue built before. The injectors for the XUV-FEL and HACL branches are on the brink of the current state of the art. The repetition rate of the high charge, high brightness photocathode gun required for the XUV-FEL injector is restricted by the average power of the klystrons available which is at the moment at a level of 200 kW. The repetition rate is currently limited to 1 kHz but in principle may be increased to 10 kHz and beyond by using a superconducting photocathode gun.

The performance of the HACL injector is limited by the charge lifetime of GaAs photocathodes. These are susceptible to back ion bombardments and the lifetime will not exceed 24 hours. An alternative to the GaAs gun would be a gun based on more robust alkali photocathodes like Cs_2Te. However, emission of high average currents from Cs_2Te has not yet been studied. Another option might be K_2CsSb multialkali photocathodes which have demonstrated high enough quantum efficiency [7]. Extra high power normal conductive RF guns [8,9] under development do not provide emittance low enough and the required 100% duty factor. An alternative superconducting RF gun has the problem of removing from the superconducting cavity 50 W of laser power required for production of 100 mA current.

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