# THE PRE-INJECTOR LINAC FOR THE DIAMOND LIGHT SOURCE

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*Abstract*

The Diamond Light Source (DLS) is a new medium-energy high brightness synchrotron light facility which is under construction on the Rutherford Appleton Laboratory site in the U.K [1]. The accelerator facility can be divided into three major components; a 3 GeV 561 m circumference storage ring, a 158.4 m circumference full-energy booster synchrotron and a 100 MeV pre-injector linac. This paper describes the linac design and plans for operation.

## LINAC PARAMETERS

The DLS linac generates an electron beam suitable for injection through the linac-to-booster transfer line (LTB) into the booster synchrotron. The Diamond master oscillator frequency is 499.654 MHz† and linac operation is synchronised to this at 2.997924 GHz‡. Two modes of operation are planned; short-pulse mode, in which a single electron bunch is injected into one booster RF bucket, and long-pulse mode in which a train of single bunches is injected into the booster at an operational frequency of 500 MHz.

Table 1: Linac parameters

| Parameter | Short-pulse mode | Long-pulse mode |
|---|---|---|
| Energy | 100 MeV | 100 MeV |
| Pulse-to-pulse energy variation | 0.25% rms | 0.25% rms |
| Relative energy spread | 0.25% rms, ±1.5% full spread | 0.25% rms, ±1.5% full spread |
| Repetition rate | Single shot to 5 Hz | Single shot to 5 Hz |
| Normalised emittance (1σ) | 50 π mm mrad in each transverse plane | 50 π mm mrad in each transverse plane |
| Pulse duration | 1 ns | 300 ns to 1000 ns |
| Output charge | 50 pC to 1.5 nC | 50 pC to 3 nC |
| Pulse purity | 1% of total charge | - |

The linac will be capable of performing continuous top-up injection in both short-pulse and long-pulse modes. During top-up, 1-5 Hz repetitive operation in both modes will be maintained for 1-10 seconds, and repeated every 1-5 minutes, or single pulses (or pulse trains in long-pulse mode) will be repeated every 10-300 seconds.

## LINAC COMPONENTS

The linac is supplied by ACCEL Instruments GmbH under a turn-key contract, with Diamond Light Source Ltd. providing linac beam diagnostics, control system hardware and standard vacuum components. The design chosen for the DLS linac is very similar to that operating at the Swiss Light Source (SLS) [2, 3], also supplied by ACCEL Instruments.

### *Electron gun*

The electron gun assembly contains an EIMAC YU 171 thermionic dispenser cathode with integrated heater and grid. Cathode lifetime is estimated to be several thousand hours. The gun pulser contains two independent driving circuits, a 1 ns fwhm pulser driving the cathode for short-pulse operation, and a 500 MHz sine-wave driver modulating the cathode. Separation of the two driving circuits avoids the excitation of the cathode-grid resonance by the 500 MHz Fourier component of the short-pulse waveform. The electron gun is maintained at -90 kV relative to earth.

### *Bunching system*

The linac buncher will consist of the following components:

- Subharmonic pre-buncher (SHPB): one copper single-cell 500 MHz standing-wave cavity
- Primary bunching unit (PBU): one copper four-cell constant-impedance travelling-wave structure operating in 2π/3 mode at 3 GHz
- Final bunching unit (FBU): one copper sixteen-cell constant-impedance travelling wave structure operating in 8π/9 mode at 3 GHz

The SHPB acts to velocity modulate the non-relativistic electron beam emerging from the gun, compressing the pulse before it passes into the PBU. In the PBU, the beam is given a 3 GHz S-band structure, and then this S-band beam is accelerated to a relativistic level in the FBU, and the S-band bunches are further compressed. Phase velocities in the bunching units are 0.6 c in the PBU and 0.95 c in the FBU.

A laminar flow tent will be used for SHPB installation to minimise the possibility of multipactoring during linac operation. Use of a driving amplifier with a higher duty

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†Rounded to 500 MHz for the remainder of this document
‡Rounded to 3 GHz for the remainder of this document

cycle than that used at the SLS is expected to reduce conditioning time during commissioning.

### *Accelerating structures*

Two identical accelerating structures of the DESY S-Band Linear Collider Type II design [4] will be used to accelerate the bunched beam up to the final energy. They are both constant-gradient copper structures operating in $2\pi/3$ mode at 3 GHz.

Table 2: Accelerating structure parameters

| Parameter | Value | Unit |
|---|---|---|
| Length | 5.2 | m |
| Number of cells | 156 | |
| Group velocity | 0.02 | c |
| Phase velocity | 1 | c |
| Filling time | 740 | ns |
| Shunt impedance | 51 | MΩ/m |
| Operating temperature | 40 | °C |

### *RF system*

The high-power RF system is driven by two 3 GHz modulator units, each with one Thales TH2100 klystron. This klystron is rated at 35 MW peak pulsed power and is driven by a 350 W pulsed preamplifier and a thyratron-switched LC line-type pulse-forming network. The first modulator-klystron unit drives the PBU, the FBU and the first accelerating structure, and the second modulator-klystron drives the second accelerating structure. The accelerating structures are designed to give 50 MeV beam acceleration for input power of 19 MW. Power is transmitted to the accelerating and bunching structures through $SF_6$-pressurised waveguide. The interface between the $SF_6$-pressurised region and the linac vacuum envelope is a vertical ceramic window. The 500 MHz master oscillator signal is used to drive the electron gun and the SHPB, and to ensure synchronisation of the high-power RF with the Diamond booster and storage ring.

### *Additional components*

In order to compensate for RF defocusing and space-charge blow-up of the beam, 31 solenoids are required in the low-energy region of electron beam for energies up to 10 MeV. One solenoid is mounted at the electron gun and 30 are in the low-energy region around the bunchers and at the beginning of the first accelerating structure. In the 50 MeV drift section between the two accelerating structures, a quadrupole triplet is used to match the output of the first structure into the second structure. Alignment correction of the beam will be carried out by steerers mounted at different positions along the linac. Two different types of steerer are used, a Helmholtz type for use within solenoids, and an iron-cored type for use outside the solenoids.

Linac vacuum will be maintained at $10^{-8}$ mBar by a Gamma Vacuum 500T 500 l/s ion pump mounted at the gun, a 150T 150 l/s ion pump on the SHPB and six 100T 100 l/s ion pumps along the linac assembly. Evacuated waveguide on the linac-side of the ceramic windows leading to the PBU, the FBU and the two accelerating structures are pumped independently by one 100T 100 l/s ion pump each. The electron gun and SHPB will be protected against downstream leaks by a VAT series 75 fast-closing valve system mounted at the entrance to the second accelerating structure.

## DIAGNOSTICS AND COMMISSIONING

Installation of the linac will begin in October 2004, and the large accelerating and bunching structures will be shipped to DLS in January 2005. Commissioning of the linac will take place before summer 2005. Commissioning and acceptance of the linac will require partial construction of the LTB, and supply of diagnostics by DLS.

The LTB extends 25.6 m from the end of the linac to the booster injection point and includes two 15° dipole bends and eight quadrupoles. Linac and LTB diagnostics are listed in table 3 and shown in figure 1. Temporal structure of the beam will be measured by wall current monitors in the linac at the gun exit, and in the LTB before the first dipole. Emittance will be measured by analysis of the image recorded on an OTR screen after a quadrupole doublet at the beginning of the LTB. Energy measurements will be made on an OTR screen in a dispersive length of the LTB between the two dipoles. Faraday cups and integrating current transformers will be used to measure beam charge. YAG screens, OTR screens and beam position monitors will used to check beam alignment. Linac diagnostics have been manufactured to SLS designs [5]. LTB diagnostics include a new beam position monitor system, a Bergoz integrating current transformer and a novel design of Faraday cup in the beam stops [6]. The two dipoles in the LTB are fitted with synchrotron radiation ports to retain the option of using optical diagnostics in the LTB.

Table 3: Linac and LTB diagnostics

| Diagnostic | Linac | LTB |
|---|---|---|
| Wall current monitor | 1 | 1 |
| Faraday cup | 2 | 2 |
| YAG screen | 4 | 2 |
| OTR screen | 1 | 4 |
| Beam position monitor | - | 7 |
| Integrating current transformer | - | 3 |
| Synchrotron radiation port | - | 2 |

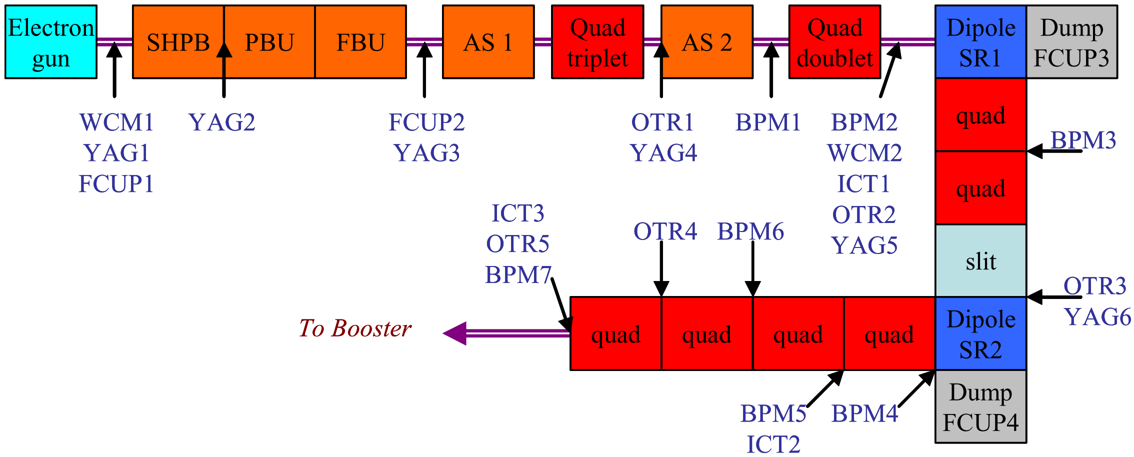


Figure 1: Schematic of linac and LTB showing principal components and locations of all diagnostics.

## MODELLING OF LINAC AND LTB

The behaviour of the linac and LTB has been modelled using the electron-linac particle-dynamics code PARMELA. Modelling is valuable for commissioning the linac, beam-steering through the LTB, in regular operation and for gaining an understanding of the physical processes taking place. Figure 2 illustrates the bunching of the beam in single pulse mode, and shows the temporal structure expected at the exit of the gun, at the input to the first accelerating structure (AS1 in), and at WCM2 in the LTB before the first dipole: the broad gun pulse is bunched into S-band buckets by the PBU and this structure is maintained through the linac and LTB to the booster injection.

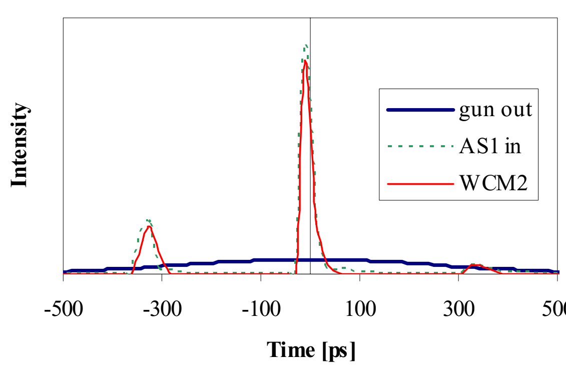


Figure 2: Bunching of the beam in short-pulse mode.

A summary of a PARMELA energy spectrum analysis is shown in figure 3. The beam is accelerated to around 5 MeV by the bunching units and then beyond the minimum booster acceptance energy of 100 MeV by the two accelerating structures. With the linac parameter settings chosen for this simulation there is a tail visible in the spectrum recorded at the OTR before the first dipole (OTR2), although the dispersive effects of the two dipoles remove this tail before the beam passes OTR5 at the end of the LTB. One of the goals of linac commissioning is to minimise the tail in the energy spectrum. The tail in the energy spectrum is a particular issue in relatively high charge long-pulse mode when beam loading in the accelerating structures reduces the field seen by electrons at the tail of the bunch train. To compensate for this effect, an energy defining slit will be used between the two LTB dipoles. Figure 3 also illustrates the expected transfer of around 50% of the beam in the required narrow energy window above 100 MeV from linac exit to booster injection.

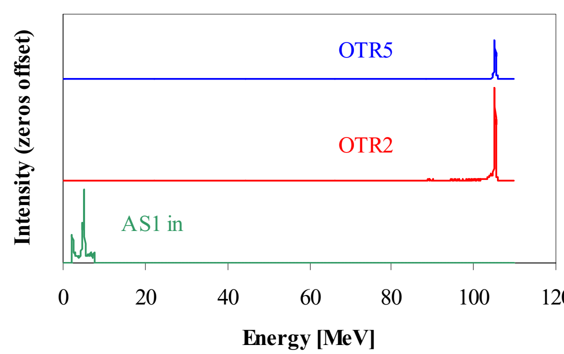


Figure 3: Energy spectrum in linac and LTB.

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