COMMISSIONING OF THE DIAMOND PRE-INJECTOR LINAC

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Abstract

Commissioning of the linac for the Diamond Light Source (DLS) was completed in October 2005. The linac was supplied by Accel Instruments, with DLS providing beam diagnostics, beam analysis software, control system hardware and standard vacuum components. Much of the beam analysis was carried out using the first part of the Linac to Booster transfer line (LTB) which was designed and built by DLS. Operation of the linac and LTB at 100 MeV in long-pulse and short-pulse modes of operation was demonstrated, and all operational parameters were measured to be within specification.

CONSTRUCTION AND INSTALLATION

The DLS pre-injector is a 100 MeV electron linac containing two identical accelerating structures of the DESY S Band Linear Collider Type II design, together with a three stage bunching section and a triode gun with a thermionic dispenser cathode. The linac is driven by two modulators, each with one Thales TH2100 klystron. A full description of the linac, including design specifications has been presented previously [1]. The linac was installed at DLS by Accel Instruments from December 2004 to August 2005. The high-power klystrons were commissioned into a water load in May 2005 and accelerating structure conditioning was completed by August 2005. 100 MeV operation was achieved on the 7th of September 2005 and beam commissioning continued until mid-October 2005. Figure 1 is a photograph of the completed linac looking towards the gun with the second accelerating structure in the foreground.

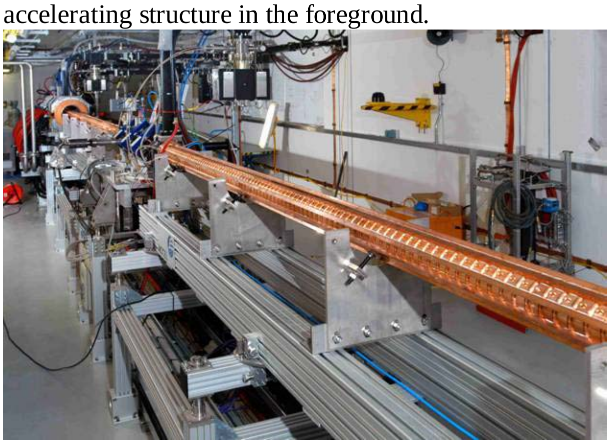

Figure 1: The completed DLS linac.

MEASUREMENT AND DIAGNOSTICS

Commissioning measurements were carried out using the diagnostics indicated in Fig. 2. In this figure, the accelerating structures are labelled AS1 and AS2, dipoles are D1 and D2 and quadrupole doublets and triplets are labelled Q2 and Q3 respectively. Beam generated by the linac could run directly to a beam dump, or be directed into a second beam dump by a dipole. The second dipole was disabled in order to isolate the linac from the booster tunnel. YAG and OTR screens were used for beam alignment at all points along the linac and LTB. The most heavily used diagnostics for commissioning were:

- the wall current monitor at the exit of the linac, labelled WCM2 in the figure, which was used for measurement of beam longitudinal properties
- the OTR screen labelled OTR3 between the dipoles, which was used for energy measurements
- the screen labelled OTR2 before the first dipole, which was used to calculate emittance and Twiss parameters at the exit of the linac
- Integrating current transformer ICT1 before the first dipole, used to measure bunch charge.

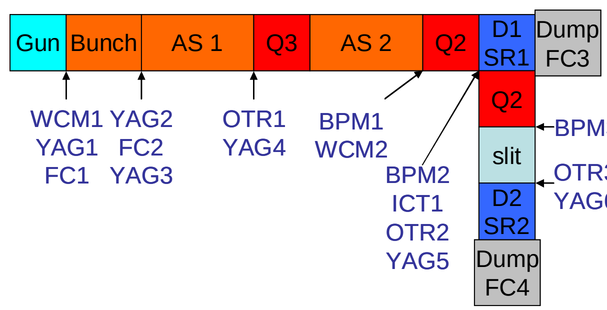

Figure 2: Diagnostics in linac and LTB.

Linac commissioning measurements were carried out at 1 Hz and 5 Hz repetition rate and it was confirmed that performance was independent of repetition rate.

SINGLE BUNCH MODE

Pulse width and charge

Beam pulse width was measured at WCM2 using a 10 GHz oscilloscope. This WCM was constructed according to an SLS design with a nominal bandwidth of 5GHz. Figure 3 shows oscilloscope traces taken without, and with the subharmonic prebuncher (SHPB), demonstrating its operation.

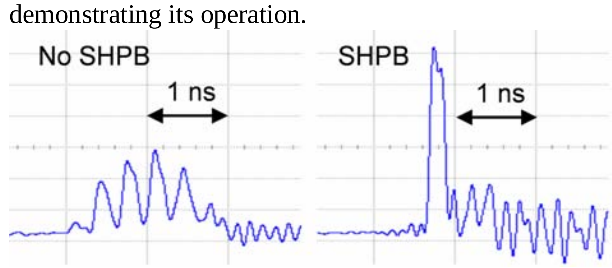

Figure 3: Beam at linac exit without (left) and with (right) SHPB recorded with wall current monitor.

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A Gaussian fit to the bunched curve has a sigma value of 77 ps. Full width at half maximum of the peak is 185 ps; this measurement is probably limited by the bandwidth of the WCM.

A typical bunch charge measurement was 2.1 nC at ICT1. Bunch charge can be reduced to any value below this by adjusting the grid voltage on the gun.

Energy

LTB dipoles were manufactured by Danfysik. Calibration data can be used to carry out an energy measurement at the screen OTR3. Figure 4 is a histogram of intensity measured across the screen expressed in energy units demonstrating that the linac is able to exceed the minimum energy requirement of 100 MeV.

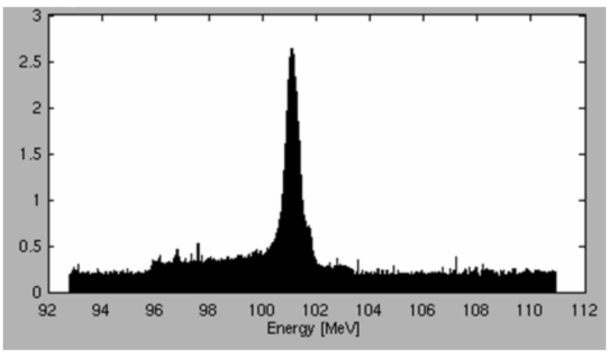

Figure 4: Energy spectrum measured at OTR3.

Pulse to pulse energy variation

It was established that jitter in beam position measured at OTR3 was caused by energy variation in the beam rather than by instability in LTB dipole power supply, which allowed pulse-to-pulse energy variations to be measured. Scanning the beam across the screen with the dipole allowed the dispersion at the screen to be determined. A dispersion value of 27 cm at OTR3 was calculated using this method, comparing well to the calculated values of 25.8 cm to 29.0 cm for the different dipole 1 currents used, based on first-order calculations using dipole and quadrupole field and gradient calibrations.

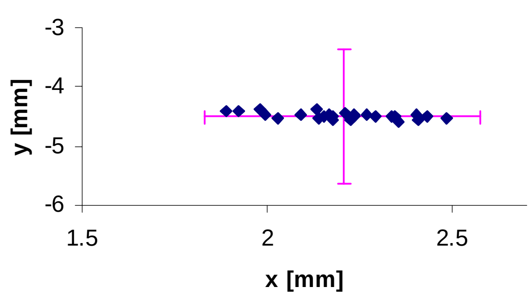

Figure 5: Shot-to-shot position jitter

Shot-to-shot jitter at a single fixed dipole current is shown in Fig. 5. For comparison, the 1σ values of a double Gaussian fit to the beam spot on the screen are also shown.

Jitter values for this measurement, expressed as a percentage of the total energy, are 0.04% standard deviation, and 0.2% full spread of the distribution of jitter values. Statistical analysis of 88 measurements gives a standard deviation of 0.05% and a full spread of 0.21%.

Normalised emittance

Beam emittance was measured by scanning the first quadrupole doublet in the LTB and performing a best-fit analysis to the beam on the screen OTR2, with data weighted according to the quality of the individual Gaussian fit. A typical measurement of horizontal parameters is shown in Fig. 6, with blue circles indicating the measured beam widths at the different quadrupole values, and the red crosses the best fits. 90% confidence limits for the values are also shown.

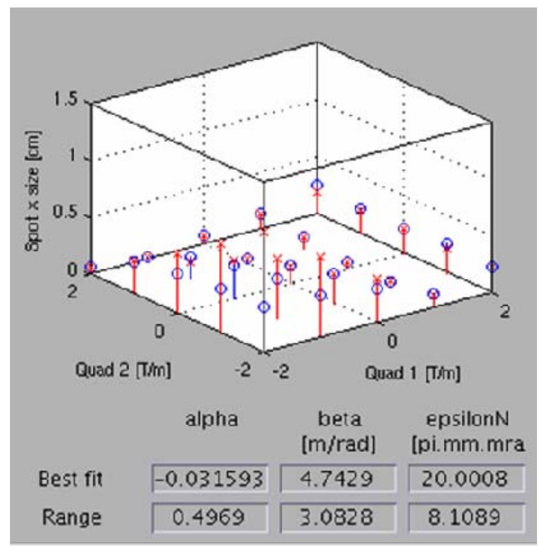

Figure 6: Measurement of emittance and Twiss parameters.

Twelve measurements of beam emittance were made during the commissioning. Linac parameters were similar for each measurement, with values of x emittance falling between 10 π mm mrad and 20 π mm mrad. Y emittance values were consistently between 10 π mm mrad and 30 π mm mrad.

Twiss parameters showed a similar consistency, with alpha values in both x and y around zero, and beta values for x and y generally between 2 m and 5 m.

Relative energy spread

Beam energy spread can be measured from the spectrum shown in Fig. 4. Steerers in the LTB were used to align the beam as well as possible through the centre of the quadrupoles

As the emittance and Twiss parameters of the beam are known, then a zero energy-spread beam size can be calculated to be equal to $\sqrt{\beta \cdot \varepsilon}$, allowing the actual energy spread to be calculated from the measured beam size. In the case shown in Fig. 4, nearly all of the beam size can be accounted for by the $\sqrt{\beta \cdot \varepsilon}$ term with a remaining Gaussian energy spread of 0.13%. There is a small tail visible in the distribution on the low-energy side of the peak but this was not considered significant.

Single bunch purity

Single bunch purity can be estimated from Fig. 3. No populated 500 MHz buckets can be seen in the bunched figure, and so there is no evidence to suggest that bunch purity is a problem. A precise measurement of bunch purity will be possible during the fill of the storage ring.

Pulse to pulse time jitter

The jitter in the delay between the timing pulse and the beam pulse measured by WCM2 was recorded using the 10 GHz oscilloscope. The standard deviation of the jitter of 101 pulses was 9 ps and the full range of the distribution was 40 ps; both values are comfortably within the specification of 100 ps.

MULTI BUNCH MODE

Bunch train length and charge

Bunch trains were measured at WCM2 at lengths between 300 ns and 1000 ns. Figure 7 shows a typical measurement, showing both the entire pulse envelope of 450 ns length, and two sub-ns individual pulses from the train.

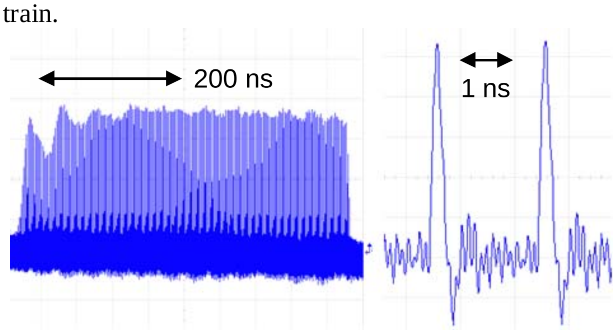

Figure 7: Multi bunch mode WCM2 trace: Entire pulse train (left) and detail (right).

Bunch charges over 4 nC were recorded by ICT1. Charge in the bunch train can be controlled by adjustment of the gun pulsing voltage.

In initial booster and storage ring commissioning, the linac was used with a 200 ns bunch train to limit stray radiation, with typically 1.7 nC recorded at linac exit, 1.6 nC at the end of the LTB and 1 nC extracted from the booster.

Energy

Energy measurements in multi-bunch mode were carried out as in single mode above. Linac operation up to 103 MeV was demonstrated.

Pulse to pulse energy variation

Energy variation results for multi-bunch mode were similar to those in single bunch mode: analysis of a set of 70 measurements gave a standard deviation of scatter of 0.05% and a full spread of scatter of 0.16%.

Normalised emittance

Twelve measurements of beam emittance were made during the acceptance tests. Linac parameters were again similar for all measurements. Normalised emittances in both x and y are within the specified maximum of 50 π mm mrad for all measurements.

Alpha values in both x and y are again around zero, and beta values for x and y generally between 2 m and 5 m. Similarity of emittance and Twiss parameters in single bunch and multibunch modes reflects the fact that the linac parameters for both modes are virtually identical, and only differ in gun operation.

Relative energy spread

Energy spread in multibunch mode was similar to that in single bunch mode, with most of the beam width attributable to the $\sqrt{\beta \cdot \varepsilon}$ term. Values comparable to the single bunch case (<0.2%) were measured.

Pulse to pulse time jitter

Jitter was again measured on the 10 GHz oscilloscope. Standard deviation of the delay between trigger and WCM2 pulse was 11 ps and the full range was 61 ps.

SUMMARY

The Diamond linac has been installed and tested. Performance to specification has been verified in long pulse and short pulse mode at 1 Hz and 5 Hz. A summary of specification and measurements is given below

Table 1: Measured linac parameters.

Parameter	**Specification**	**Single bunch**	**Multi bunch**
x emittance [π.mm.mrad]	< 50	17.9	16.2
α		-1.1	-0.2
β [m]		3.7	2.8
y emittance [π.mm.mrad]	< 50	27.1	10.8
α		-0.3	0.1
β [m]		3.1	1.9
Charge [nC]	> 1.5, 3	2.1	4.8
pulse width [ns]	< 1	~0.2	~0.2
Jitter [ps]	< 100	11	11
Energy variation [%]	< 0.25	0.1	0.1
Energy spread [%]	< 0.5	0.2	0.2

REFERENCES

[1] C. Christou, V. Kempson, K. Dunkel and C. Piel, “The pre-injector linac for the Diamond Light Source”, LINAC 2004, Lübeck, August 2004, p. 84, http://www.jacow.org.