ENHANCEMENTS TO THE DIAMOND LIGHT SOURCE PRE-INJECTOR LINAC

C. Christou, S. J. Singleton and V. C. Kempson, Diamond Light Source, Oxfordshire, UK

Abstract

Modifications have been made to the Diamond pre-injector linac to improve beam stability and to increase the scope of operation of the system. New modes of operation are described and RF stability studies are presented. Operational experience is summarised, and options for future development are considered.

MODES OF OPERATION

The DLS pre-injector is a 3 GHz, 100 MeV linac delivering up to 3 nC in a bunch train of up to 1000 ns, or a single bunch of up to 1 nC. It has a bunching section and two identical accelerating structures driven by two Thales TH2100 klystrons, and a thermionic DC gun [1].

Beam from the linac is delivered through a full-energy booster to the 3 GeV storage ring. For user operation, beam is injected as required, usually topping up twice a day to the present operating level of 225 mA. During fills the linac and booster are cycled together at 5 Hz

Linac single-bunch operation has recently been incorporated into the Diamond top-up application [2] and into an automated single bunch filling routine for the storage ring, both implemented in Python. For both applications, the linac gun and booster extraction timing is set each shot so that the bunch is injected into the bucket with lowest charge relative to a programmed fill pattern. Linac bunch charge is kept constant for top-up, but is programmed during the single bunch fill to generate a smooth fill in the minimum time: high-charge bunches are first injected into empty buckets, and charge is reduced as the bucket approaches its target. Bunch charge is controlled by setting the bias on the triode gun, as illustrated in Figure 1. Top-up uses low bunch charge, whereas single bunch fill covers the entire range. Single bunch injection efficiency into the booster is 80% at low bunch charge falling to below 50% at high bunch charge. Injection efficiency studies are continuing, with attention being paid to booster chromaticity on injection [3].

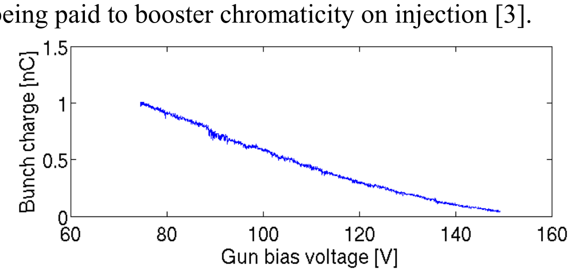

Figure 1: Single bunch charge as a function of gun bias.

Since the beginning of user operations in January 2007 most storage ring fills for user operation have used the multibunch mode of the linac, with trains of 144 buckets injected every 120 buckets over two-thirds of the ring. The 24 bucket overlap overcompensates for the 30 ns rise-time of the linac long-pulse envelope, and generates small peaks in the storage ring fill pattern [4]. The single bunch fill generates a very smooth fill, as shown in Figure 2. The smooth fill from buckets 100 to 600 is much better than that could be achieved by multibunch injection. This figure also illustrates the hybrid fill, which can be routinely generated for users on request. Hybrid fill may be generated by a multibunch two-thirds fill followed by single bunch injection, or by using the single bunch fill for the entire fill. Switching fill modes is quicker, because of the higher charge available in multibunch mode, but the automatic single bunch fill is simpler to carry out.

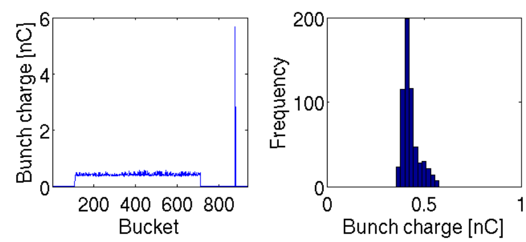

Figure 2: Hybrid fill generated using single bunch fill and histogram of bunch charge over two-thirds fill.

Long-duration tests of linac and booster reliability have been carried out in preparation for routinely offering top-up to users. Figure 3 summarises a continuous linac and booster run (with three short breaks for storage ring fills), showing a very reliable bunch charge delivered to the booster with a mean and standard deviation of 0.125 nC and 0.014 nC respectively over 24 hours.

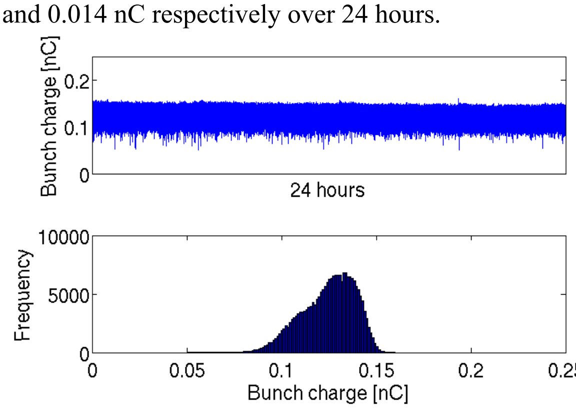

Figure 3: 24 hour run of linac and booster showing the beam delivered to the booster (top) and histogram of bunch charge (bottom).

A recent test of the complete top-up application is summarised in Table 1. At the start of top-up the gun bias was set so that the number of shots per top-up cycle was around 10 to reduce the variation in charge along the bunch train to 10% or less while minimising the disturbance of the stored beam. The number of shots to be fired in each cycle is calculated by the top-up software from the loss of current during the previous cycle, using the average charge injected per shot over the last 10 cycles. Linac bunch charge was consistent over the test, and resulted in a stable, reproducible top-up cycle.

Table 1: Summary of Top-Up Operation Test

Duration of test	7 hours
Fill pattern	Two-thirds fill
Mean storage ring current	199.875 mA
Storage ring current range	199.652 mA - 199.875 mA
Period between top-ups	2 minutes
Average shots per top-up	9.22
Current stability	0.043%
Mean charge in BTS	0.068 nC
Mean BTS to SR efficiency	73.05%

STABILITY AND RELIABILITY

A stable linac beam is essential for reliable operation of Diamond with minimum beam losses at booster injection. Continuous application of a constant phase, constant power RF signal to the prebuncher cavity has cured multipacting there, and locking the gun heater power supply and booster dipole to a common 50 Hz oscillator derived from the timing system rather than the mains supply removed the largest variation in booster injection efficiency[4]. A slow variation of booster current still remained after these improvements, with the standard deviation of a moving sample of booster current increasing when the mains frequency drifted from 50 Hz. This was a linac energy effect and is shown in Figure 4.

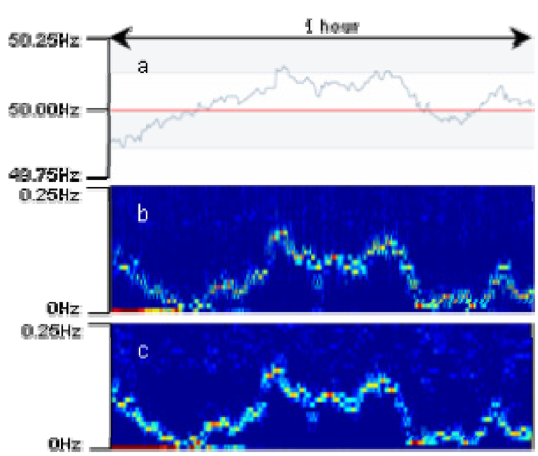

Figure 4: (a) Mains frequency, (b) frequency spectrum of booster current and (c) frequency spectrum of linac beam energy recorded over one hour.

The frequency spectrum of the booster current and the linac energy measured at a BPM in a dispersive part of the LTB correlate strongly with the deviation of the mains frequency from 50 Hz. No such oscillations were seen in the klystron preamplifier, and so it was clear that the oscillation was generated in the klystrons.

Locking the mains-driven klystron filament heaters to the same 50 Hz signal as the gun and the booster dipole removed this effect, as can be seen from Figure 5 in which one klystron filament heater is driven from the mains, and one is driven from the 50 Hz oscillator; the spectral content of the klystron locked to the 50 Hz signal has been removed.

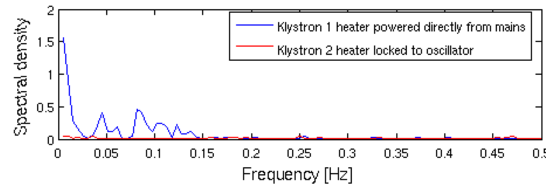

Figure 5: Comparison of klystrons with heater powered by mains (blue) and locked to the timing oscillator (red).

Sensitivity of the linac LLRF to the operating temperature in the controls rack has been noted and is controlled by enhanced cooling of this rack [4]. Further analysis of klystron operation in Figure 6 shows that klystron amplification is roughly linear over the range used in normal operation, usually > 30 W. If the preamplifier output is increased then the klystrons can be moved towards saturation and so the effect of the preamplifier thermal droop will be reduced. Preamplifer output is currently limited by cable losses at 3 GHz. Reconfiguration of the LLRF to reduce losses will also have the benefit of reducing the operating voltage of the klystrons and therefore reduce klystron arcing further.

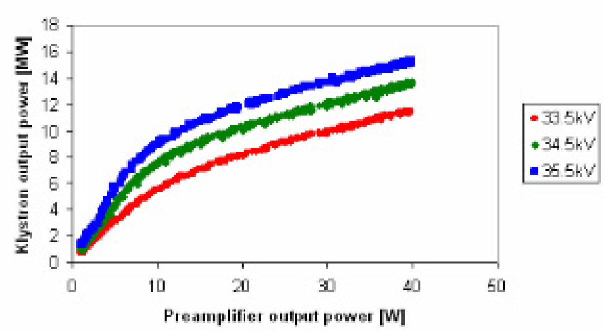

Figure 6: Klystron operation at different values of modulator PFN charging voltage.

Minimisation of klystron arcing is essential for reliable operation of top-up. At the moment klystron arcing is only a problem during klystron start-up following a machine shut-down, when the voltage must be brought up in a slow controlled manner to recondition the gun. A Matlab script has been developed for this. Klystron reconditioning takes roughly ten minutes, after which the arc rate is low, for example there were no arcs in either klystron in either the 24 hour injector test or seven hour top-up tests above. The operating point of the klystron filament is also reviewed annually to minimise arcing, and the filament voltage has been dropped twice in 2 V increments since initial commissioning of the klystrons.

Lifetime is monitored by calculation of klystron perveance during operation. The perveance record of one of the two klystrons since beginning of user operations is shown in Figure 7, showing no significant drop in perveance over this period. The spikes on the plot are artefacts recorded during klystron turn-on and turn-off. The performance of the second klystron is similar.

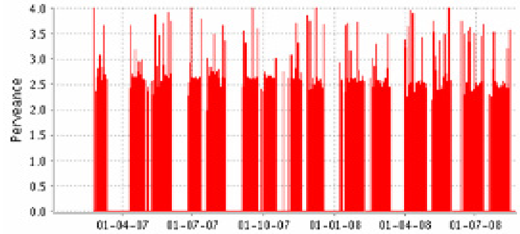

Figure 7: Klystron perveance record.

SINGLE KLYSTRON OPERATION

Perveance monitoring can be used to give early warning of klystron cathode failure, allowing replacement in a shutdown as far as possible, but unexpected klystron failure may still occur during user operation. One spare klystron is held on site, but standard operation is impossible for the duration of the klystron change and recommissioning. Operation of the injection system with one klystron has therefore been investigated, and injection of beam into the storage ring has been achieved with low-energy single klystron linac operation. Table 2 is a comparison of linac beams generated by one and two klystrons. Some increase of beam energy is possible by running the single klystron at a higher power.

Table 2: Single and Double Klystron Operation

	One klystron		Two klystrons	
Energy	44.9 MeV		99.9 MeV	
Energy spread	0.3 %		0.3 %	
	x	y	x	y
ε_N [mm.mrad]	32.7	42.6	39.6	39.2
α	-1.28	-0.22	-1.11	-0.50
β [m/rad]	5.89	0.72	2.47	2.60

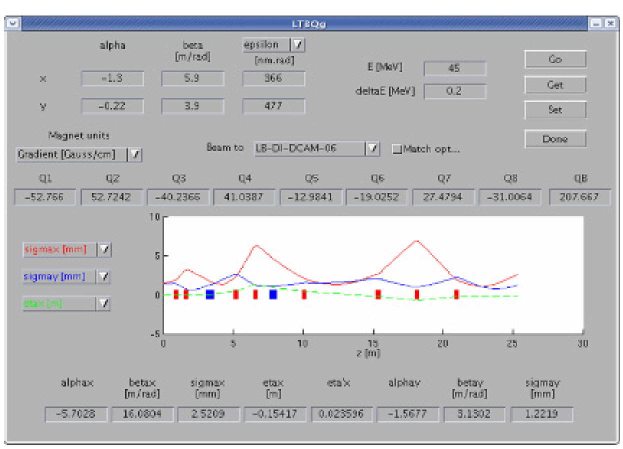

Figure 8: LTB quadrupole current tool.

Operation of the linac with one klystron requires changes to LTB and booster. Quadrupole settings for the LTB at reduced energy were calculated with the LTBQg tool, which performs a least-squares minimisation of the beam size along the transfer line whilst constraining the Twiss parameters at the LTB entrance and exit [5]. Figure 8 shows LTB parameters calculated using this tool.

Injection into the booster was achieved by scaling all magnets at injection according to the reduced beam energy and then empirically optimising the values, this involved modifying the quadrupole power supplies to operate at a lower start value for the ramp. Injection efficiency into booster and storage ring is currently much lower for single klystron operation, but it is expected that this can be improved by further optimisation of operating parameters. Again, booster chromaticity on injection is being studied.

Single klystron operation is only possible by powering the first accelerating structure and drifting through the second structure, and so studies are underway to introduce a switching mechanism in the WR284 waveguide network at the output of the klystrons as shown in Figure 9. This would allow accelerating structure 1 to be powered from klystron 2. Such a switching network is installed in other pre-injector linacs [6, 7].

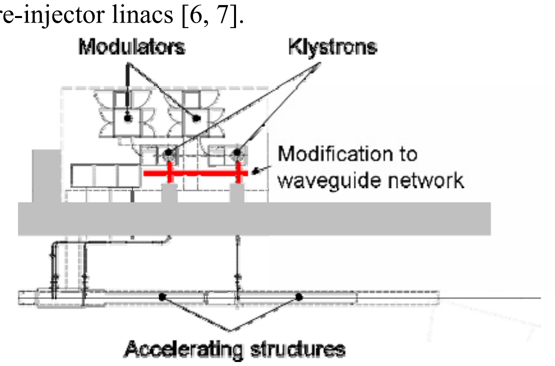

Figure 9: Waveguide modification for klystron switching.

SUMMARY

Two new modes of operation have been developed in the second year of operation of Diamond: firstly, the Diamond pre-injector linac has been fully incorporated into top-up operation, and secondly high-uniformity storage ring fill has been delivered to users by operating the linac in a programmed single bunch mode. A new fault-mode of operation using one of the two linac klystrons is also under development. Linac stability has been improved by modification of the klystron filament power circuit, and options for further stability and reliability enhancements have been identified in both low-level RF and high-power RF distribution.

REFERENCES

[1] C. Christou, et al, EPAC 2006, Edinburgh, p 3187.
[2] R. P. Walker et al, EPAC 2008, Genoa, p 2121.
[3] C. Christou et al, EPAC 2008, Genoa, p 2157.
[4] C. Christou et al, PAC 2007, Albuquerque, p 1112.
[5] R. Bartolini et al, EPAC 2006, Edinburgh, p 3065.
[6] B. Pottin et al, PAC 2005, Knoxville, p 755.
[7] G. D'Auria et al, EPAC 2008, Genoa, p 2160.