FURTHER OPTIMISATION OF THE DIAMOND LIGHT SOURCE INJECTOR

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Abstract

Optimisation of the Diamond Light Source injector has continued since user operation started in January 2007. Beam losses have been minimised by injector tuning and stabilisation, and high level software has been developed to characterise booster and injection parameters. Operation in top-up and single bunch storage ring fill modes are reported, and low-energy linac fault-mode studies are detailed.

THE DIAMOND INJECTOR

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 includes two identical accelerating structures and klystrons, a three stage bunching section and a thermionic DC gun [1]. The full-energy booster has a single five-cell copper cavity driven by an IOT amplifier [2]. The linac and booster are cycled together at 5 Hz. The booster has a single kicker for on-axis injection, and a preseptum, septum and fast kicker for extraction. Injection into the storage ring is through four identical kicker magnets and one septum [3].

LINAC AND BOOSTER STABILITY

Thermal drifts in the linac LLRF, multipacting in the pre-buncher and sensitivity of the booster dipole power supply to drifts in the mains frequency were dealt with in the first year of operation [4]. The 50 Hz linac gun heater was synchronised to the 5 Hz booster dipole cycle using a timing system oscillator to eliminate the effects of the mains frequency drift. A small linac energy variation arising from the beating of the mains-driven filament heater with the oscillator was eliminated by locking the klystron filament heaters to the same oscillator.

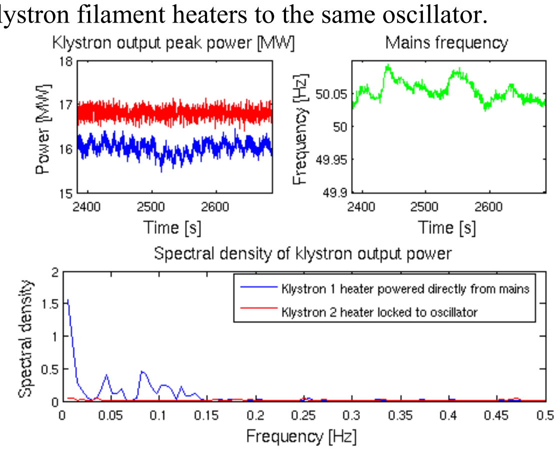

Figure 1: Comparison of klystrons with heater powered by mains (blue) and locked to the timing oscillator (red). Slow power beat is absent for the synchronised heater.

Stabilisation of the linac and booster injection components has allowed work to progress on injection efficiency into the booster, in particular for low-charge single bunch operation, where injection efficiency into the booster from the LTB has increased from below 50% to over 70% in the last year.

The booster RF is cycled from 1 kW to 55 kW every injection cycle. The sine wave RF ramp used initially has recently been changed to a $\sin^4$ dependence on booster dipole current to follow ramp losses. This has had no observable effect on the beam, and has the advantage of reducing the total RF power demand by 45%.

TURN-BY-TURN BOOSTER ANALYSIS

Booster tune has been routinely measured since initial commissioning using the FFT of turn-by-turn BPM or stripline data [5]. In the last year, the turn-by-turn analysis has been extended to measure booster chromaticity by establishing betatron tune evolution through the ramp over several different measurements, each taken at a different master oscillator frequency.

Booster chromaticity calculated from tune measurements across a range of master oscillator frequencies from 499.648 MHz to 499.656 MHz are shown in figure 2, together with the design values of chromaticity calculated including the natural chromaticity and eddy current effects in the booster vessel. Sextupoles were turned off for this measurement.

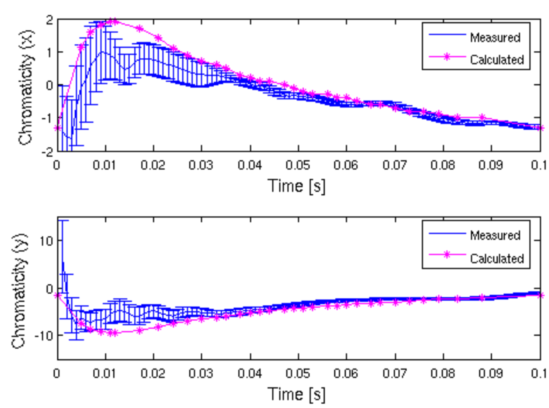

Figure 2: Booster chromaticity in the horizontal plane (top) and vertical plane (bottom).

Agreement between design and measured values is generally good, but there are some differences in the early part of the ramp. This may explain the fact that the current settings of the sextupoles, which are based on theoretical settings to achieve a chromaticity of +1, +1, still result in some beam losses with high charge single bunches, and this is the subject of ongoing work. The uncertainty in the measurement is greatest at the beginning of the ramp because of the small linac energy jitter, measured in the LTB to be 0.09 MeV.

Booster cavity voltage through the ramp, V_{RF}, can be calculated from the synchrotron frequency f_s according to

$$V_{RF} = \sqrt{{U_0}^2 + \left(\frac{\left(f_s / f_r \right)^2}{\alpha \cdot h / 2 \cdot \pi \cdot E} \right)^2} ,$$

where U_0 is the energy loss per turn, f_r is the machine revolution frequency, α is the momentum compaction factor, h is the harmonic number and E is the beam energy. A cavity voltage measurement for a sine wave ramp is shown in figure 3. Results are consistent with cavity probe power measurements [2]. Deviations from the programmed sine curve are caused by nonlinearities in amplification and uncertainty in frequency measurement.

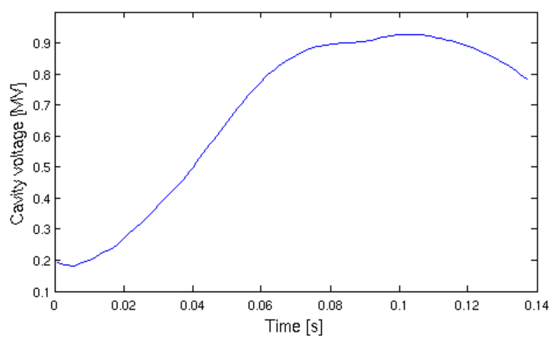

Figure 3: Booster cavity voltage

STORAGE RING INJECTION ANALYSIS

The turn-by-turn tools developed for booster analysis can also be used for the storage ring during injection, since the beam is excited by the injection kickers. Tune shifts with single bunches have been studied extensively [6, 7], but bunch train behaviour is less widely studied. A measurement at PEP II ascribed tune shifts to quadrupolar wake effects generated by the non-circular resistive vacuum chamber [8]. This mechanism causes the tunes to drift in different directions in the two transverse planes. This effect in Diamond is shown in figure 4.

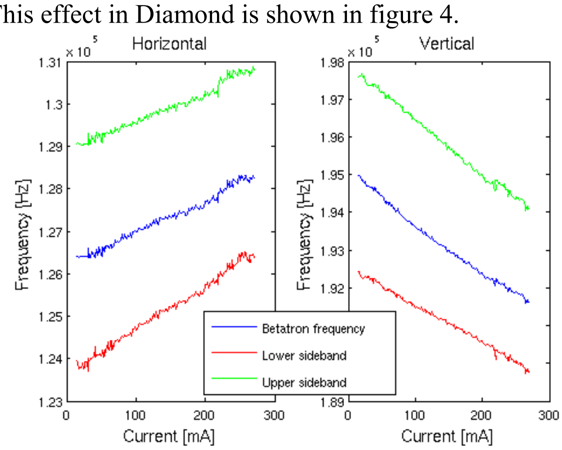

Figure 4: Drift in betatron tune and sidebands

Shifts in betatron frequency in Diamond have been automatically logged on injection since mid-2007, and have stayed constant, averaging +7.3 Hz/mA in x and -14.9 Hz/mA in y despite the introduction of several insertion devices into the storage ring during this time.

The profile of the betatron tune peak and its sidebands can be accurately reproduced by the Fourier transform of three Gaussian peaks, all decaying exponentially. A measurement and reconstruction are shown in figure 5. The simulated turn-by-turn record of the best-fit shows the same beating as the BPM record

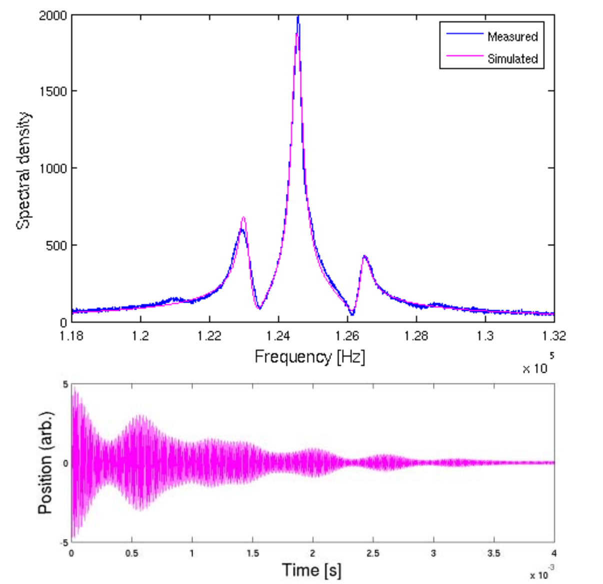

Figure 5: Measured and reconstructed tune profile (top) and reconstructed turn-by-turn trace (bottom).

The intensity and positions of the sidebands relative to the central peak change during the current stack [9], but for a given beam current with constant ring impedance they are chromaticity-dependent, and so can be used as a passive measurement of chromaticity for each stack. Cross-calibration of the sideband ratio with a chromaticity measurement derived from a master oscillator frequency scan allows a passive chromaticity measurement to be made automatically each injection.

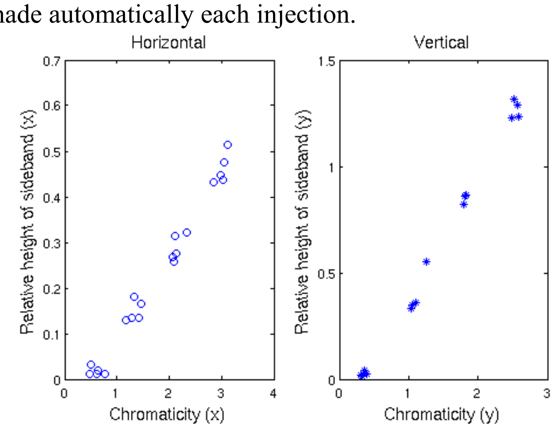

Figure 6: Ratio of lower sideband intensity to betatron tune peak intensity in horizontal and vertical planes.

PREPARATION FOR TOP-UP

Storage ring injection kicker vessels, power supplies and controls software have all been modified over the last year in an effort to minimise the effect of the injection kick on the stored beam. In a recent test, beam disturbances of ±300 µm and ±150 µm were recorded in x and y respectively from turn-by-turn BPM measurements and an integrated loss of beam intensity of less than 5% was measured from the U27 in-vacuum undulator on the Materials and Magnetism Beamline. Work is continuing to minimise the disturbance on the beam; recent fine-tuning of operating currents and timing of the four kickers indicates that the kick can be further reduced.

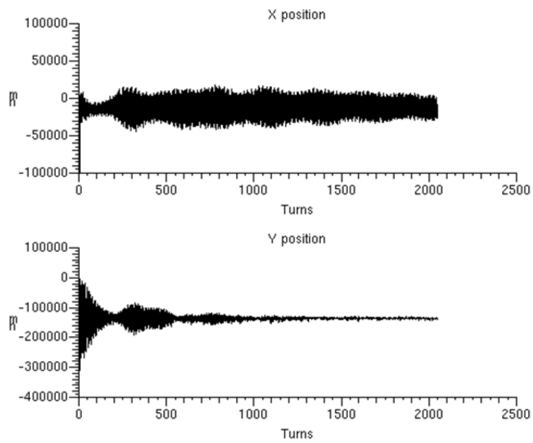

Figure 7: Turn-by-turn BPM measurement of kick following fine tuning of injection kickers. Maximum kicks are ±30 µm and ±140 µm in horizontal and vertical planes respectively.

A top-up control tool has been implemented in Python to maintain the storage ring fill as close as possible to any desired pattern [10]. Five to ten single bunch shots are injected every two minutes, sufficient to maintain the beam current within 0.5% of the target value. Different fill patterns have been successfully maintained over periods of several hours using this tool, and it is ready to be put into operation for users.

An extension of the top-up application has also been completed, in which the initial fill of the storage ring is also performed using single-bunch injector mode. This filling mode has the advantage over the normal multibunch filling routine of being able to fill any arbitrary pattern in the ring, and does not require a switch between injector multibunch mode and single bunch mode for top-up. The single bunch fill mode has been routinely used to generate a hybrid fill pattern consisting of a two-thirds ring fill and one isolated higher-charge bunch [4].

SINGLE-KLYSTRON LINAC OPERATION

One high-power klystron drives the bunchers and first accelerating structure of the linac, and the second klystron drives the second accelerating structure. Operation of the linac with one klystron would allow injection to be maintained even in the event of the failure of the second unit. Table 1 shows beam properties of the linac running on the first klystron alone, compared with normal two-klystron operation.

Table 1: 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

Apart from the obvious energy difference, single and double klystron operation is similar. Injection trials were carried out with a single klystron and an adjusted LTB and booster, and beam was successfully injected into the storage ring in this mode in early 2008. Overall transfer efficiency from linac to storage ring is still low in this mode and so studies are continuing, with the chromaticity on injection into the booster a particular issue. The beam energy in single klystron mode may also be increased by driving the accelerating structure at higher power.

SUMMARY

Stability enhancement and characterisation of the Diamond injector has continued in the second year of operation, and progress has been made in preparations for top-up and in the development of a single klystron mode of operation.

REFERENCES

[1] C. Christou et al., “Commissioning of the Diamond Pre-injector Linac”, EPAC’06, p. 3185.
[2] C. Christou et al., “The Diamond Light Source Booster RF System”, EPAC’06, p. 1295.
[3] V. C. Kempson et al., “Pulsed Magnets and Pulser Units for the Booster and Storage Ring of the Diamond Light Source”, EPAC’06, p. 3341.
[4] C. Christou and V. C. Kempson, “Operation of the Diamond Light Source Injector”, PAC’07, p. 1113.
[5] V. C. Kempson et al., “Commissioning of the Booster Synchrotron for the Diamond Light Source”, EPAC’06, p. 3344.
[6] A. S. Müller et al., “Studies of Current Dependent Effects at ANKA”, EPAC’04, p. 2011.
[7] Y. H. Chin, CERN/LEP-TH/88-05, 1988.
[8] A. Chao et al., Phys. Rev. S. T., Accelerators and Beams, 5, 11101 (2002).
[9] S. Myers, “Stabilization of the fast head-tail instability by feedback”, PAC’87, p. 503.
[10] R. P. Walker et al., “Preparation for Top-up Operation at Diamond”, this conference.