ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPA161

ADAPTABLE GUN PULSER SUITABLE FOR SINGLE BUNCH AND PROGRAMMED MULTIBUNCH TOP-UP AND FILL OF STORAGE RING LIGHT SOURCE

C. Christou, D. Child and A. Tropp, Diamond Light Source, Oxfordshire, UK
J. Hares and S. Palmore, Kentech Instruments Ltd., Wallingford, Oxfordshire, UK

Abstract

Diamond Light Source has been operating in top-up mode for users since late 2008. To date, Diamond's electron gun has operated in single-bunch (SB) mode for multiple-shot top-up of user beam, and multibunch (MB) mode for storage ring fill. The uneven bunch-to-bunch charge of the MB train is visible in the storage ring and so the fast MB fill must be followed by a slower SB correction before beam can be given to users. A new pulser has been developed that will generate a flat, fast-rising 500 MHz train of electron bunches from the gun, enabling a uniform fill of the storage ring without SB correction. Arbitrary bunch-by-bunch shaping of the train can be used for MB fill and top-up of any required fill pattern, thus exploiting the greater charge available in MB mode to reduce the number of top-up shots and consequent disturbance to users.

TOP-UP AT DIAMOND

Top-up injection at Diamond is used to maintain constant conditions for users. Top-up repeats every 10 minutes and consists of multiple SB injection, with gun, linac and booster firing five times per second to maintain 300 mA storage ring current. The storage ring fill pattern is monitored optically, and on each cycle the most depleted bunches are filled, so that any arbitrary fill pattern can be maintained [1].

Diamond uses a four-kicker bump injection scheme, and any mismatch of the injection kickers disturbs the beam. Up to now, the effect has been managed by matching the kickers as well as possible and by countering induced oscillations with storage ring pinger magnets [2, 3]. Further benefit can be gained by increasing the charge per top-up shot, thus reducing the number of shots per cycle and therefore the duration of the disturbance. Upgrade of the gun cathode pulser has increased the charge delivered to the storage ring in SB mode, and incorporation of an Arbitrary Waveform Generator (AWG) into the pulser has preserved the option of individual bunch control even when delivering trains of over 100 bunches in one high-charge MB top-up shot.

GUN PULSER DESIGN

The original pulser board, operational for users since 2007, uses an Eimac YU171 thermionic triode delivering a pulsed beam at 90 keV. The cathode is pulsed negative in SB mode, and the grid is pulsed positive in MB mode, with a 500 MHz RF signal added to a pedestal pulse to define the bunch train. Cathode current is a very non-linear function of grid/cathode voltage and so small disturbances in drive voltage can lead to large modulation of beam current. This is compounded by the lumped capacitance of the electron source spoiling the impedance match, resulting in disturbances to the drive waveform.

The new pulser, designed and manufactured by Kentech Instruments, was installed in 2023 and is operated as a drop-in upgrade to the old pulser, driving the same gun. The 2007 RF amplifier has a relatively narrow bandwidth with a slow start and end. For the upgrade it was planned to use an AWG to generate and shape the pedestal, but tests showed that the AWG and pulse amplifier alone have sufficient bandwidth and amplitude to generate the complete signal without any additional RF. A schematic of the new system, operating with no RF amplifier, is shown in Fig. 1.

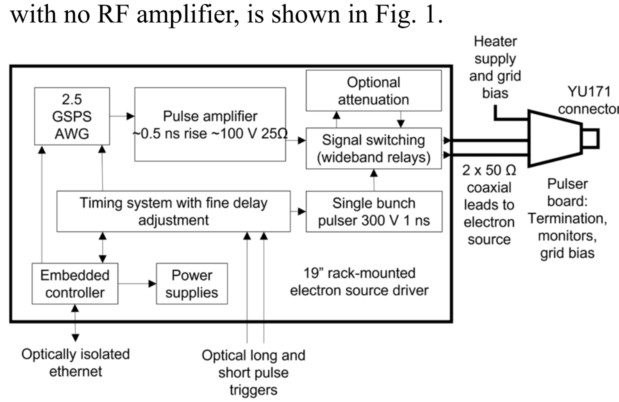

Figure 1: System schematic.

An AC grounded grid and a driven cathode arrangement was chosen for the new pulser. This allows a reduced capacitive load at the expense of the driver also needing to support the beam current. The programmability of the AWG allows compensation for the additional loading produced by the beam current. The cathode drive is resistively terminated at the electron source. With this arrangement the heater sees the RF, so the supply is inductively decoupled from the RF at the source.

The low-level AWG output drives a pulsed amplifier which typically produces a peak voltage of -100 V into a 25 Ω load, this being the chosen drive impedance for the electron source. The output from this amplifier is a negative arbitrary waveform of duration up to 1 µsec. The sample rate and bandwidth are such that the amplitude of individual bunches in the burst can be programmed. Typically, there are five samples per 500 MHz cycle and one sample in five is programmed to set the bunch height. In addition to AWG drive the source driver provides a legacy single bunch mode in which a GaN based pulser

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPA161

produces a ~1 ns 300 V pulse into the 25 Ω feed to the source. The rack-mounted driver is shown in Fig. 2.

Figure 2: Rack-mounted driver.

The new pulser matching board is shown in Fig. 3. It carries the heater supply and couples the pulse to the cathode, providing a resistive termination. Monitors are provided including a proportional monitor of the signal at the cathode plus a grid bias monitor.

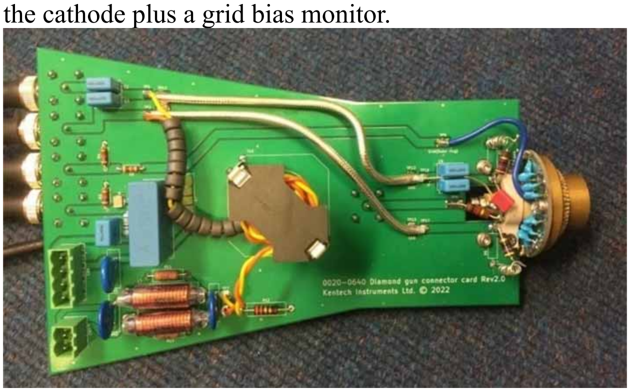

Figure 3: Pulser matching board.

A further development of the matching board and connector, designed in collaboration with ANSTO [4] using an improved gun connector has been tested and proven but is not yet in routine operation.

The trigger jitter of the AWG is ~10 ps rms. This jitter is well within the acceptance window of the pre-buncher. Clean single bunches at arbitrary positions with arbitrary amplitudes are readily programmed at the linac output.

A so-called "agile programming mode" is provided in which the DAC memory control allows successive records to have completely different waveforms. This allows successive 5 Hz MB shots to have different bunch pattern, enabling top-up and fill of any arbitrary storage ring fill pattern.

The firmware in the driver allows the interactive adjustment of individual bunches. In the initial trials a flat bunch train was obtained simply by adjusting the amplitude of each bunch as measured at the linac exit.

SINGLE BUNCH TOP-UP

The improved performance of the new SB pulser results in a significant increase of the charge delivered by the gun for the same bias. This extra gun charge is preserved through the linac, as can be seen in Fig. 4, which shows the bunch charge measured by a wall-current monitor at the linac end.

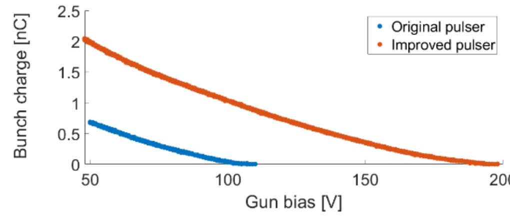

Figure 4: Bunch charge measured at the end of the linac with the old and new pulsers.

Diamond has been operating with the new pulser in SB mode since early 2023 and consequently the number of shots per top-up cycle has fallen from 100-150 to below 50. Figure 5 shows the number of top-up shots averaged per run in the past year, with the asterisk indicating the use of the new pulser.

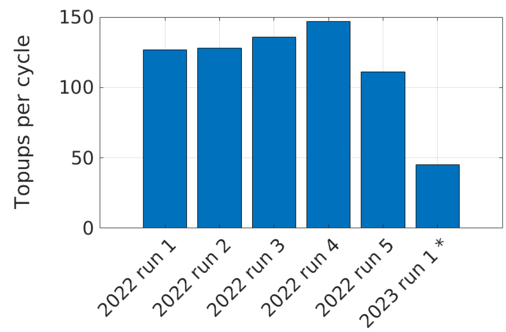

Figure 5: Average number of top-up shots per cycle.

MULTIBUNCH TOP-UP AND FILL

Enhanced bunch charge is also seen in MB operation with the new pulser. Figure 6 shows total charges in 120-bunch trains for old and new pulsers. Because the new pulser acts on the cathode whereas the old pulser pulses the grid, the effect of increasing bias is different in the two cases. The top-up control tool has been modified to incorporate this difference for the new pulser.

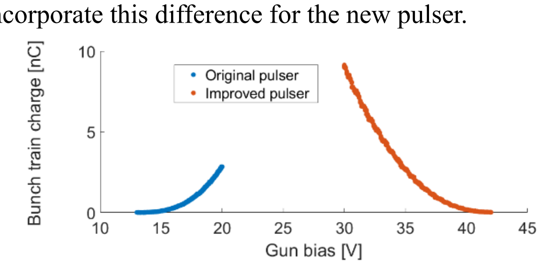

Figure 6: Total charge of bunch train at linac end with old and new pulsers.

The charge in MB mode can be increased beyond the values shown in Fig. 6 by changing the bias appropriately, but the benefit of greater pulse charge is limited at values much above 10 nC per shot because the 3 GeV losses at such high charges trigger radiation monitors which stop the injection process. Of greater significance for an MB top-up scheme is the ability to use the AWG to shape the pulse train. The upper trace in Fig. 7 shows a bunch train generated by the old pulser, with the ringing of the pulse

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPA161

visible on the bunch train envelope. In the lower trace, the ripple on the pulse train is reduced by the better match and can be eliminated by editing the AWG drive signal for individual bunches.

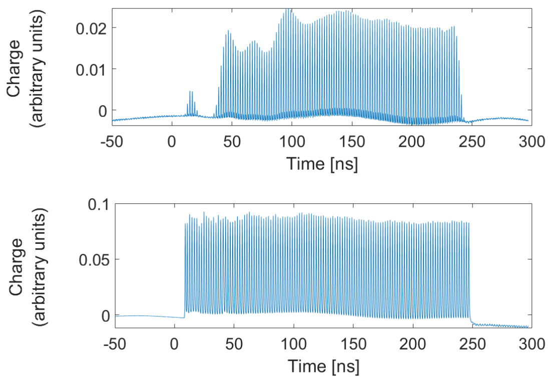

Figure 7: MB train from the old pulser (above) and new pulser (below).

The AWG can also be used to generate any bunch train directly at the gun. For example, Fig. 8 shows a hybrid pattern consisting of a short bunch train followed by an isolated high-charge single bunch. This ability to generate arbitrary patterns at the gun allows any pattern in the ring to be filled and topped up in MB mode to take advantage of the high charge and to remove the requirement for a slow switch from MB mode to SB mode during the storage ring fill.

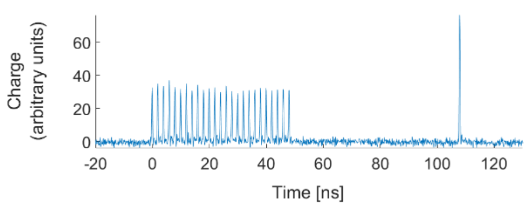

Figure 8: Hybrid bunch train from gun.

As MB charge increases, beam loading in the linac becomes more apparent. Figure 9 shows storage ring fills with the old pulser with bias 16 V ("low charge") and 18 V ("high charge"). With low charge, the fill pattern resembles the gun output but beam loading with high charge results in an energy spread along the bunch train so only part of the train is captured in the booster. In Fig. 9, the correct energy is in the middle of the train.

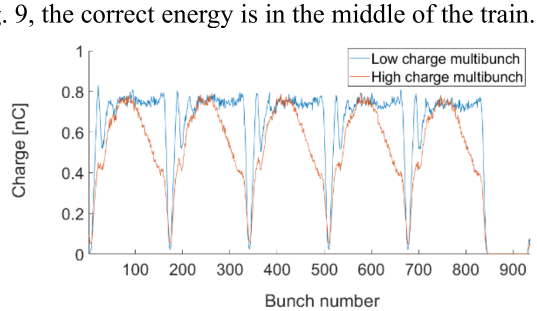

Figure 9: Storage ring fill patterns with lower (above) and higher (below) total bunch train charge.

The freedom to shape the pulse at the gun allows the operator to compensate for this unequal capture in the booster by enhancing charge at the beginning and end of the bunch train. Preservation of the flat bunch train with the new pulser can be verified in the booster to storage ring transfer line (BTS) before injection by measuring the signal from a BPM pickup in the BTS. A typical trace is shown in Fig. 10.

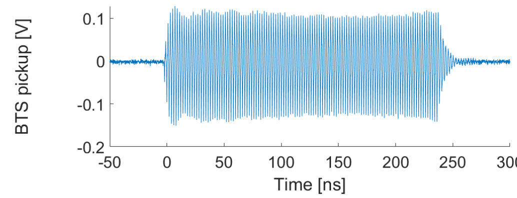

Figure 10: Bunch train in BTS.

The ability to shape the bunch train also allows individual bunch charges within the train to be defined by the fill pattern measurement, enabling any storage ring fill pattern to be maintained with an MB top-up, and can also be used to maintain a flat storage ring fill in the case when lifetime varies from bunch-to-bunch, for example with transient beam loading. Figure 11 shows an MB storage ring fill with the new pulser, with no gaps, overlaps or beam loading effects seen in Fig. 9. The noise on the flat top is a diagnostic effect.

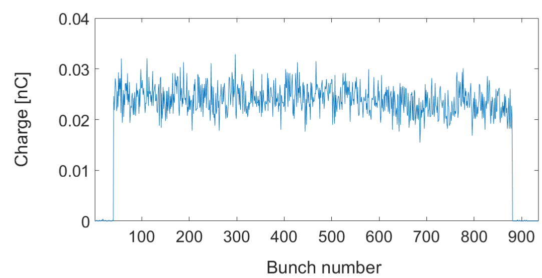

Figure 11: Storage ring fill with new pulser.

SUMMARY

A new pulser has been built and installed in the gun at Diamond Light Source. This new pulser can generate a single bunch of electrons from the thermionic gun, or a train of bunches suitable for top-up and fill of the Diamond storage ring. Total charge per shot from the gun in both modes is enhanced with the new pulser, and the incorporation of an arbitrary waveform generator in the pulser unit allows the independent precise definition of charge in every bunch in the multibunch train. The ability to generate a programmed bunch train, both uniform and irregular, allows a rapid fill with any storage ring fill pattern, and enables a multibunch top-up scheme that exploits the increased charge available in a multibunch train to minimise disturbance of user beam.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-MOPA161

REFERENCES

[1] R. P. Walker, "Recent developments at Diamond Light Source", in *Proc. 23rd Particle Accelerator Conf. (PAC'09),* Vancouver, Canada, May 2009, paper TH4PBC02, pp. 3169-3171.

[2] C. Christou *et al*., "The first eighteen months of top-up at Diamond Light Source", in *Proc. 1st Int. Particle Accelerator Conf. (IPAC'10),* Kyoto, Japan, May 2010, paper WEPEA066, pp. 2636-2638.

[3] R. T. Fielder *et al*., "Operational use of pinger magnets to counter stored beam oscillations during injection at Diamond Light Source", in *Proc. 12th Int. Particle Accelerator Conf. (IPAC'21),* Campinas, Brazil, May 2021, pp. 459-462. doi:10.18429/JACoW-IPAC2021-MOPAB128

[4] M. Atkinson, private communication, 2022.