ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPRB001

NANOSECOND PULSING FOR TANDEM ACCELERATOR*

P. Linardakis†, D. C. Tempra, N. R. Lobanov, The Department of Nuclear Physics, Research School of Physics and Engineering, The Australian National University, Canberra, Australia

Abstract

A pulsed system capable of delivering up to a few microampere bursts of ions with mass range M=1 – 100 amu with a duration of approximately 1 ns is described. The system consists of a negative ion source, three frequency harmonic buncher – which uses the entire tandem electrostatic accelerator as a drift path to produce bunched ion bursts at the targets or linac entry – and high energy choppers. The buncher consists of a single acceleration gap with aligned retractable grids.

INTRODUCTION

The Heavy Ion Accelerator Facility (HIAF) at the Australian National University (ANU) operates a National Electrostatics Corporation (NEC) 14UD pelletron tandem electrostatic particle accelerator [1]. A wide array of nuclear physics experiments are carried out at the facility and there is a demand for ion beam pulsing driven by use of time-of-flight techniques in heavy ion experiments and by the injection requirements of HIAF's superconducting rf linac booster. Furthermore, the variety of experiments required pulsed beams from ion masses of 1 amu to 100 amu, all with a time width of approximately 1 ns. Due to loading limitations of the accelerator, the pulsing system must be able to bunch a large fraction (50 – 70%) of the dc beam in order to achieve efficient operation.

SYSTEM OVERVIEW

Mechanical Design

Figure 1 shows the configuration of the pulsing system around the 14UD pelletron. A three-frequency harmonic buncher operating at a fundamental of 9.375 MHz sits approximately 3.3 m above the entry slits of a NEC tandem pelletron electrostatic particle accelerator. The accelerator acts as a drift path to produce bunched ion bursts at targets or the entry of a superconducting linac. At the high-energy end of the accelerator, two closely spaced choppers operating at 37.5 MHz and 4.6875 MHz serve to remove background ions between the pulses produced by the buncher.

The buncher design evolved from a system originally from Argonne National Laboratories [2]. Figure 2 highlights three main features of the current buncher hardware. These are the electrode assembly, the resonators and the retractable electrodes.

An rf voltage is created across two electrodes that accelerate and retard ions as they pass across the 5 mm gap between two electrodes at the centre. These electrodes consist of molybdenum grids, shown in the inset of Fig. 2 with a pitch of 1.5 mm and a diameter of 24 mm orientated perpendicular to the direction of beam. The grids are mounted to copper conical support electrodes, with field extension electrode rings that sit 150 mm above and below the grids.

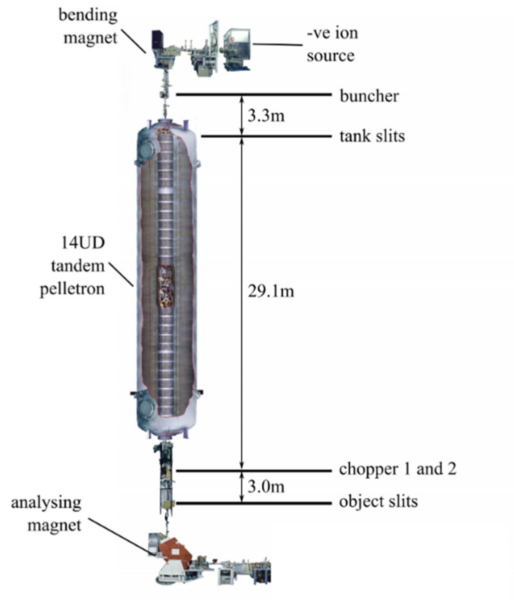

Figure 1: Configuration of beam pulsing sub-systems around the HIAF 14UD pelletron.

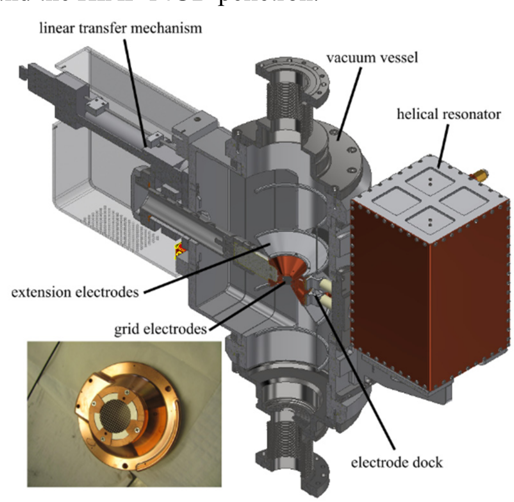

Figure 2: Retractable grid-based buncher hardware.

High-voltage rf is applied via two high-Q helical resonators. One is tuned to $f_2 = 18.75$ MHz and connects to one electrode and the other resonator is tapped such that it can be tuned to both $f_1 = 9.375$ MHz and $f_3 = 28.125$ MHz.

In the current iteration of the hardware, the buncher electrodes are able to be retracted from the ion beam path for applications, such as atomic mass spectroscopy, that

* Work supported by Australian Federal Government Superscience/EIF funding under the NCRIS mechanism
† peter.linardakis@anu.edu.au

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPRB001

do not require bunching and where beam transmission is important. The electrode assembly is cantilevered from a Vacgen (formerly VG Scienta) wide-bore z-axis linear transfer mechanism (LTM) that is driven by a stepper motor controlled via EPICS. The electrodes are driven into a dock that connects them to the resonator circuits.

Two high energy choppers consist of two flat parallel plates inside the vacuum space connected to resonant circuits on the atmospheric side. These plates are shown in Fig. 3 and are 200 mm long and 30 mm wide, with the separation being 15 mm and 10 mm for chopper 1 and chopper 2 respectively.

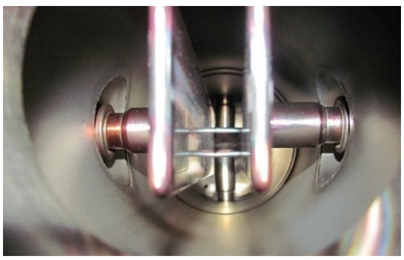

Figure 3: Chopper 1 and chopper 2 deflector plate electrodes.

The resonant circuits detune due to mechanical expansion from rf heating circuit structure and chopper 1 is particularly susceptible. To account for this detuning, control electronics employ a motor driven tuning capacitor. A hollow shaft stepper motor in conjunction with a fine pitch lead screw is used to provide a fine linear action to move to one side of a capacitor plate. This assembly is shown in Fig. 4.

Figure 4: Tuneable capacitor used to stabilise the phase of the chopper 1 resonant circuit.

System Electronics

The capacitor motor is driven by a proportional integral derivative (PID) control system that measures the relative phase error with respect to a clock reference at 9.375 MHz. This determines the motor position required to maintain the desired resonant frequency of the circuit. The phase error is measured by an Analog Devices AD8302 Gain and Phase Detector. This provides a simple and accurate method of obtaining phase and amplitude information for use in the control system [3].

The buncher LLRF control system designed is based around an Analog Devices AD9959 DDS chip to generate the required output drive signals.

This device is a four channel DDS capable of a sample rate of 500 MS/s with 10 bits of amplitude resolution. With a phase resolution of 14 bits this device is more than capable of controlling the relative phase within the required range of +/- 1°. The first three channels are used to drive the three frequency outputs. The fourth channel is used to create phase measurement reference signals for the three feedback signals. This allows the reference signals to be arbitrarily phase adjusted which allows 360° control over each channel even though the phase measurement has a limited range.

The PID control algorithm is performed by an Atmel microcontroller which updates all six control loops at a rate of 10 Hz. The microcontroller also fields requests via its Ethernet interface. Requests come in the form of TELNET commands, which give remote access and control to parameters such as phase and amplitude set points, control loop states, PID gains and the system status register.

A block diagram of the overall bunching system is shown in Fig. 5.

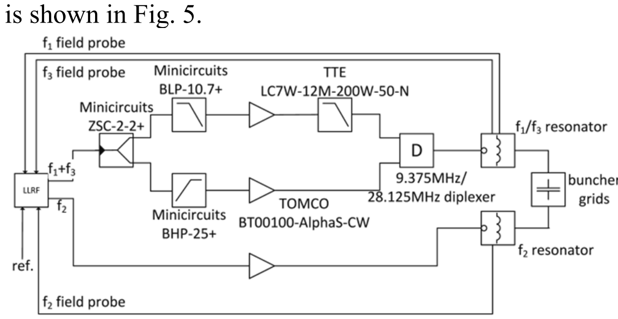

Figure 5: Bunching system block diagram.

PERFORMANCE

System Electronics Performance

The effect on long term stability of the chopper can be seen in Fig. 6.

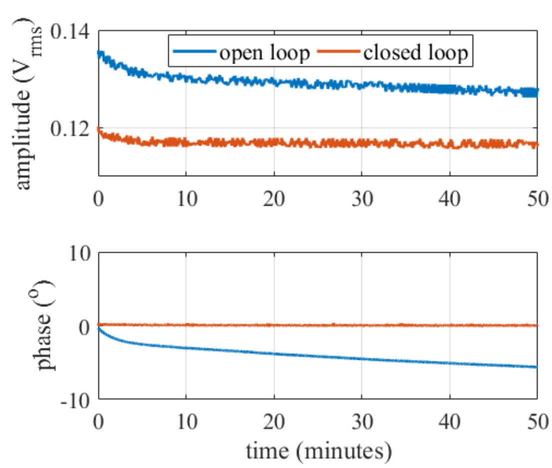

Figure 6: Chopper 1 control system performance.

ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-TUPRB001

Performance With Ion Beam

Figure 7 illustrates the effect of each bunching frequency and chopper on the beam pulse, together with the total effect and the final beam pulse profile. Here, the over-bunching of f_1 alone is clear, which is a result of the total power requirement for three frequency bunching being higher than that for single frequency bunching to achieve the same field gradient. The pulse waveform monitoring system is described in [4].

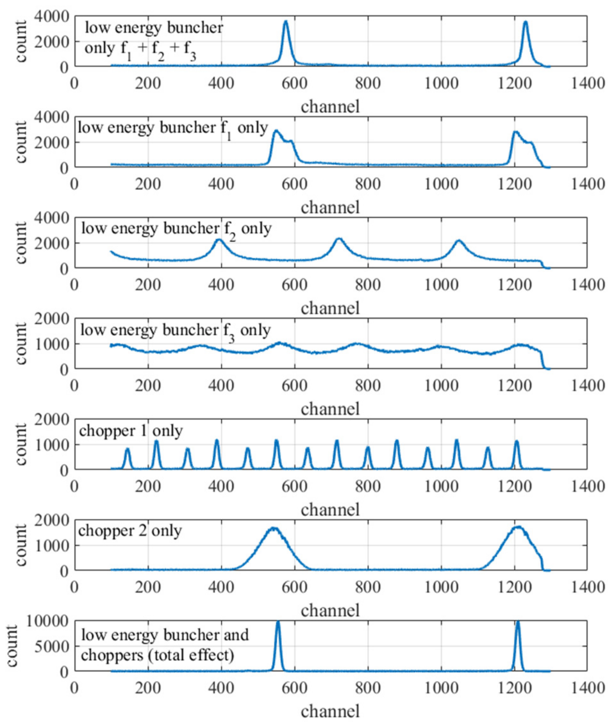

Figure 7: Effect of each component of the pulsing system on the beam timing profile for a 120 keV injection and 75 MeV 16O+6 beam (0.1634 ns per channel).

The chopper control system successfully stabilises the chopper phase and the difference between open loop and closed loop cold start is shown in Fig 8. A 1.7 ns shift in the beam pulse peak after the system was switched off for twenty minutes is avoided with the control system operational.

DISCUSSION AND CONCLUSION

The beam pulsing system used on the HIAF 14UD allows for efficient use of pulsed beams with phase stable injection into experiment end stations or the superconducting linac. The output of the buncher successfully produces an amplitude and phase stable sum of the three frequencies to produce an approximate saw-tooth wave with a large linear region of over 50% of the cycle.

This improved stability is critical when attempting to match and maintain the phase relationship between the 14UD and the superconducting linac booster.

Overall bunching efficiency using three frequencies can be measured as pulsed beam current at a faraday cup after the analysing magnet compared to a dc beam. Achievable bunching efficiency variers with ion beam mass. For injection energies of 150 keV, this ratio varies from 30% for atomic masses of around 65, to 60% for atomic masses around 16. These are generally 50% higher than can be achieved with single frequency bunching for the same beam.

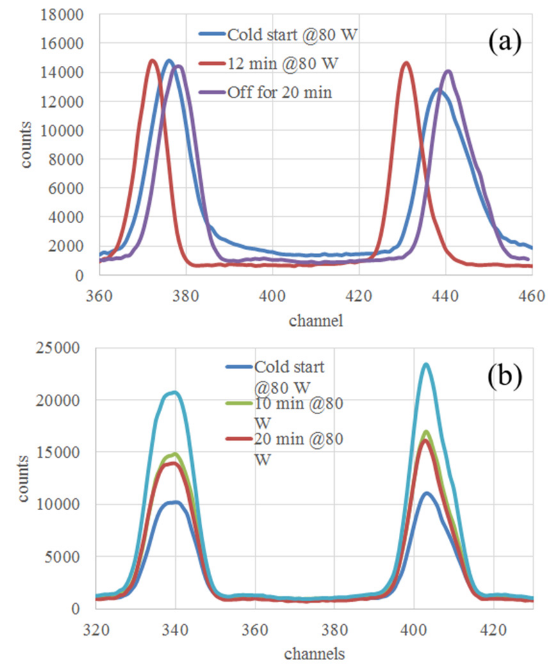

Figure 8: Comparison of beam timing profile due to chopper 1 from cold start with (a) open loop and (b) closed loop control (0.19 ns per channel).

REFERENCES

[1] T. R. Ophel, J. S. Harrison, J. O. Newton, R. H. Spear, E. W. Titterton and D. C. Weisser, "The 14UD pelletron accelerator at the Australian National University", *Nucl. Inst. & Meth.*, vol. 122, p. 227, 1974. doi:10.1016/0029-554X(74)90485-6

[2] F. J. Lynch, R. N. Lewis, L. M. Bollinger, W. Henning and O. D. Despe, "Beam buncher for heavy ions", *Nucl. Inst. & Meth.*, vol. 159, pp. 245-263, Feb. 1979. doi:10.1016/0029-554X(79)90651-7

[3] K. H. Hu, J. Chen, C. H. Kuo, D. Lee and K. T. Hsu, "Simple Amplitude and Phase Detector for Accelerator Instrumentation", *AIP Conference Proceedings*, vol. 648, pp. 523-530, Nov. 2002. doi:10.1063/1.1524441

[4] D. Tsifakis, N. R. Lobanov and P. Linardakis, "Development of a beam pulse monitor for the Heavy ion Accelerator facility", in *Proceedings of IBIC 2015*, Melbourne, Australia, pp. 27-29. doi:10.18429/JACoW-IBIC2015-MOPB001