MULTI-PUSH ENHANCED DUTY CYCLE FOR OA-TOF MASS SPECTROMETERS

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Daniel J Kenny, Steven D Pringle, Jason L Wildgoose
Waters MS Technologies Centre, Manchester, M23 9LZ, UK

OVERVIEW

- **The maximum duty cycle of conventional orthogonal acceleration Tof instruments is typically 20-25% with an average duty cycle of 15% across the mass range.**
- **Existing synchronisation techniques allow 100% duty cycle to be obtained but over a restricted mass range.**
- **Our new technique synchronises the oa-pusher with multiple masses and interleaves the synchronised masses on successive acquisitions to give a theoretical 30% duty cycle over the entire mass range**
- **Preliminary experimental data confirms that the duty cycle remains substantially constant and gives an average duty cycle of 24%.**
- **No significant degradation of mass resolution or mass accuracy is seen.**

INTRODUCTION

Conventionally, orthogonal acceleration time of flight (oa-Tof) mass analysers have been used to sample continuous beams of ions by asynchronously accelerating ions out of the acceleration region.

Figure 1(a) illustrates the basic operation of such an oa-Tof mass analyser. A continuous beam of ions passes through the pusher region out of which a fraction of the continuous beam is orthogonally accelerated. These ions are reflected by the reflectron towards the detector following the trajectory indicated by the arrow.

In this asynchronous mode, an oa-Tof is not capable of analysing 100% of the ions because a period of time between orthogonal pulses is necessary to prevent heavier ions from a preceding pulse to be overtaken by lighter ions from a subsequent pulse. The maximum duty cycle at any given m/z is determined by the geometry of the system and is typically between 20% and 25%. The duty cycle for a given mass may be calculated using the equation:

$$DutyCycle = \frac{D}{L}\sqrt{\frac{m/z}{(m/z)_{max}}}$$

where D is length of the orthogonal acceleration (pusher) region, L is the centre to centre separation between the pusher and the detector and $(m/z)_{max}$ is the maximum mass of interest.

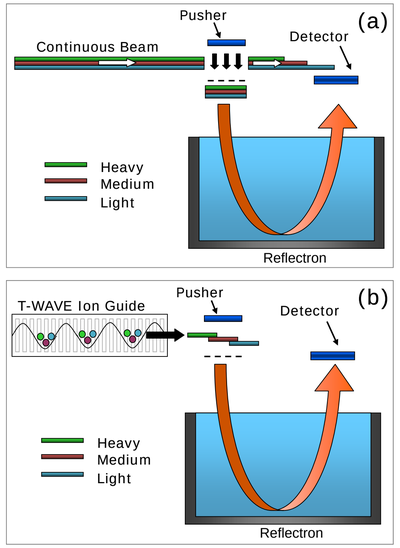

Figure 1. (a) Schematic of a conventional oa-Tof with asynchronous sampling of a continuous ion beam. (b) Schematic of an oa-Tof with an upstream travelling wave ion guide (TWIG) delivering packets of ions to the pusher.

Figure 1(b) demonstrates a method of obtaining an enhanced duty cycle (EDC), albeit over a restricted mass range. Here, a travelling wave ion guide (TWIG) has been used to partition a continuous stream of ions into packets of ions. The energising of the orthogonal accelerator is then synchronised to the time of flight between the exit of the ion guide and the pusher for a m/z of interest [1].

Figure 2 is a plot of duty cycle as a function of mass for an oa-Tof in both standard (black line) and enhanced duty cycle (red line) modes of operation. In this example the full scale m/z is 2000 and the EDC window has been set to an m/z of 200.

THEORY

In EDC mode, the pusher is only energized once per release of ions from the TWIG. However, once all of the ions have been detected from a single push, heavier ions are still passing through the pusher region. Therefore the pusher may be energized a second time (or more) to detect further mass windows.

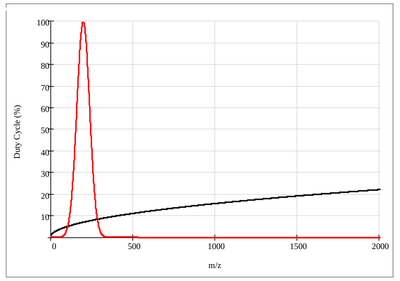

Figure 2. Plot of the asynchronous duty cycle of an oa-Tof (black line) compared to the Enhanced duty cycle (EDC) obtained by synchronizing the pusher with m/z 200 Da (red line).

Figure 3(a) shows the duty cycle which may be obtained by pushing three times for each ion packet released from the TWIG. This results in 100% duty cycle for three masses, but as low as 0% duty cycle for other masses.

However, instead of acquiring the same mass windows for each ion packet release, it is possible to change the mass windows between successive releases. Figure 3(b) illustrates the duty cycle when interleaving between two different sets of mass windows. Each distribution now only reaches a maximum of 50% duty cycle as only half of the pushes are synchronized to each. Figures 3(c) and (d) illustrate the duty cycle from each set of mass windows when interleaving between 4 and 8 sets respectively.

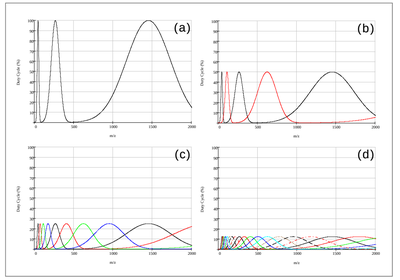

Figure 3. (a) The duty cycle obtained when pushing three times for each release of an ion packet from the TWIG; (b) the effective duty cycle when pushing three times but interleaving between two different sets of mass windows; (c) interleaving between four sets of mass windows; (d) interleaving between eight sets of mass windows.

Figures 4(a) - (d) show the overall duty cycle that is obtained when each individual contribution in figures 3(a) - (d) are combined. The overall duty cycle obtained when interleaving between two sets of mass ranges can be seen from figure 4(b) to oscillate between 50% and approximately 10% over the whole mass range. Increasing the number of interleaved mass windows to four (figure 4(c)) significantly smoothes out this oscillation as the duty cycle varies between just 28% and 32%. Further increasing the number of mass windows to eight (figure 4(d)) now completely smoothes the duty cycle to a constant 30% duty cycle.

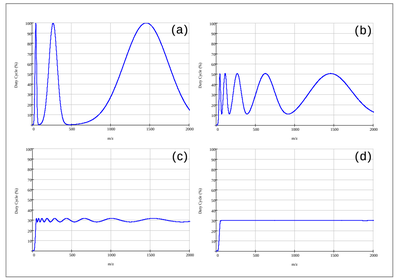

Figure 4: Summed duty cycle plots for different levels of interleaving. (a) 1 set of mass windows, (b) 2 sets, (c) 4 sets, (d) 8 sets.

EXPERIMENTAL

A standard QTof Premier (Waters Corporation) was modified to run in the new multi-push enhanced duty cycle (MP-EDC) mode of operation. Experiments were then performed to demonstrate the improvement in sensitivity that may be obtained when running in MP-EDC mode compared with standard asynchronous operation.

Collision induced fragment ion spectra of the doubly charged precursor ion of Glu-fibrinopeptide (m/z 785.842 Da) were acquired for the fragment ions in both modes of operation. For the MP-EDC experiments, the mass windows were optimized so as to obtain an approximately constant duty cycle across the entire mass range between m/z 50 and m/z 2000. This was achieved by activating the pusher three times for each release of a packet of ions from the travelling wave gas cell and by interleaving four different sets of mass windows.

RESULTS

Figures 5(a) and (b) are the spectra obtained when running in standard and MP-EDC modes of operation respectively. The vertical axis on both spectra have been normalized so that the gain in sensitivity may be directly compared.

It is immediately obvious that at low mass there has been a significant improvement in signal intensity and that even at intermediate mass there has still been more than a doubling of the signal intensity.

To get a clear comparison of the improvement in duty cycle, the ratios of the data in figures 5(a) and (b) have been plotted as a function of mass in figure 6. It can be seen from this figure that a duty cycle gain of ~6.5x is obtained at m/z 72 Da and that the gain has more than doubled all the way up to m/z 600 Da. Above this value the gain slowly decays but still remains above 1x for the whole mass range of interest.

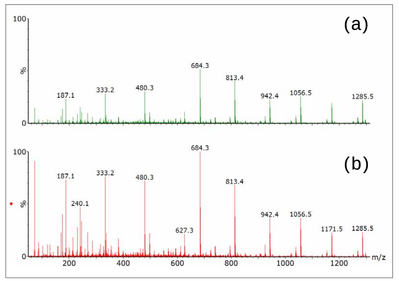

Figure 5: CID spectra for the doubly charged precursor ion of Glu-fibrinopeptide (m/z 785.842 Da). (a) Standard asynchronous acquisition. (b) The new MP-EDC mode of acquisition.

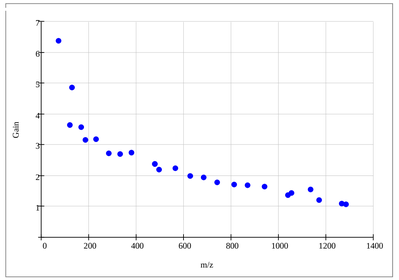

Figure 6: Duty cycle gain obtained by running in MP-EDC mode vs standard acquisition mode.

Figure 7 plots the experimentally measured duty cycle obtained using MP-EDC (red dots) and compares this with both the theoretical MP-EDC duty cycle (blue line) and that for conventional oa-Tof (black line).

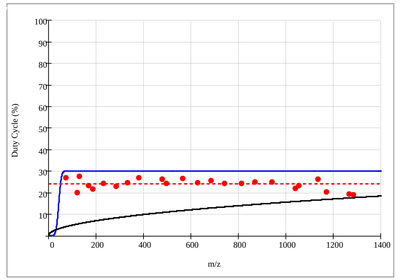

Figure 7: A comparison of the duty cycle of a conventional orthogonal TOF (black line) compared with the theoretical duty cycle of the new MP-EDC mode (blue line). Experimentally measured duty cycle values for MP-EDC are plotted as red dots with the average duty cycle shown as a dashed red line.

In general, the experimental data is lower than that expected from theory; the average measured duty cycle is 24% which is 80% of the expected 30% duty cycle. However, the presented data always remains above the standard duty cycle and the average MP-EDC duty cycle is still a 60% improvement over the average standard duty cycle. It is expected that optimization of the new technique will further improve its performance to closer to that predicted theoretically.

CONCLUSIONS

- **A new mode of data acquisition for orthogonal acceleration TOF mass spectrometers has been presented.**
- **Theory predicts that a near constant duty cycle of 30% may be achieved across the whole mass range using the new MP-EDC mode, an average increase of 2x over the average duty cycle of conventional oa-Tof.**
- **Preliminary Data has shown that a near constant duty cycle is indeed achieved with MP-EDC with an average duty cycle of 24%.**
- **At low mass, this improvement in duty cycle leads to a gain in the number of detected ions of over 6x and gains of over 2x are obtained up to m/z 600 Da.**
- **No significant degradation of mass resolution or mass accuracy is seen**

REFERENCES

[1] Pringle S.D., Wildgoose J.L., Giles K., Worthington K., Bateman R.H. In *Proceedings of the 48th ASMS Conference on Mass Spectrometry and Allied Topics, 2004*

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