PULSE LENGTHENING EXPERIMENTS ON THE FETS ION SOURCE

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Abstract

The Front End Test Stand (FETS) under construction at the Rutherford Appleton Laboratory is the UK's contribution to research into the next generation of High Power Proton Accelerators (HPPAs). Running at 50 Hz with 2 ms pulse lengths are required. This paper presents initial H^- beam currents for long pulse lengths.

INTRODUCTION

The FETS ion source [1] is a modified version of the ISIS surface Penning source. Recent work has demonstrated an H^- beam at the exit of the LEBT with a current in excess of 50 mA and a normalised RMS emittance of 0.35 π mm mrads for a 500 µs pulse length at 50 Hz.

Previous studies [2] have shown that it is possible to offset the extra power in the discharge for longer pulses with additional cooling. The following experiments show the beam current results for longer extraction voltage pulses and longer discharges.

EXPERIMENTS

Long Discharge Pulse- Extend Extraction Pulse

The main discharge is kept at 55 A, pulsed at 50 Hz with a 1.4 ms long duty cycle. This is the maximum reliable pulse length achievable with the available power supply. The extraction voltage is kept at 18 kV, and its duty cycle extended backwards into the discharge as shown in figure 1. The present extraction voltage power supply is not capable of long pulse operation at 50 Hz so its repetition rate is reduced to 3.125 Hz, but the main discharge is kept at 50 Hz.

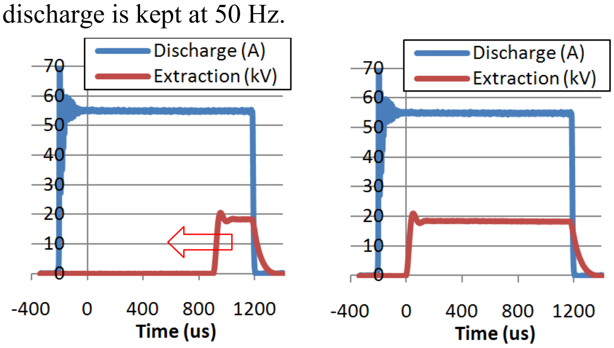

Figure 1: Extending the extraction pulse backwards into a long discharge pulse.

Figure 2 shows how the beam current measured directly after post acceleration droops as the extraction pulse is lengthened into the discharge.

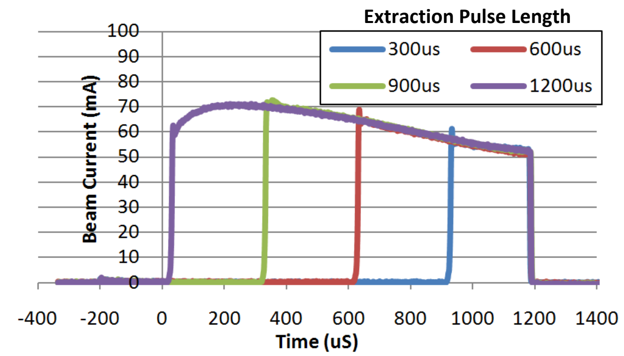

Figure 2: shows how the beam current from the source drops of as the extraction pulse is extended backwards

50 Hz vs 3.125 Hz Extraction / Moving the Pulse

By varying the timing of a short 300 µs extraction voltage pulse running at 50 Hz the effect of running a lower extraction repetition rate can be assessed. Figure 3 shows the beam current for different positions of the 50 Hz extraction voltage pulse with a 3.125 Hz long pulse extraction superimposed on top. The 50 Hz short extraction pulse beam currents are almost identical to the 3.125 Hz long pulse case, therefore the source performance can be reliably compared for lower extraction repetition rates.

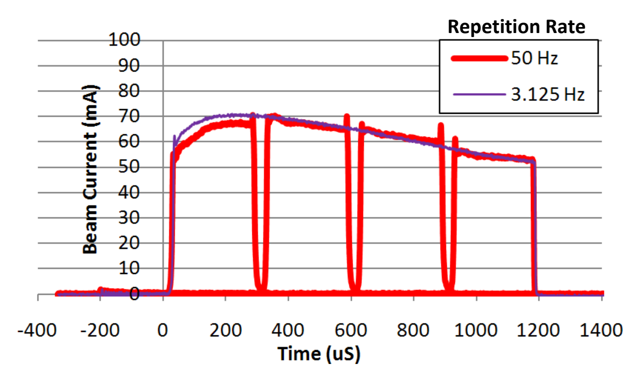

Figure 3: Comparison between 50 Hz and 3.125 Hz extraction.

Extending the Discharge Before the Extract

The next experiment is to see the effect of varying the discharge pulse length, and keeping a short extraction pulse in the last 300µs of the discharge, as shown in figure 4. The repetition rate is 50 Hz for both the discharge and extraction.

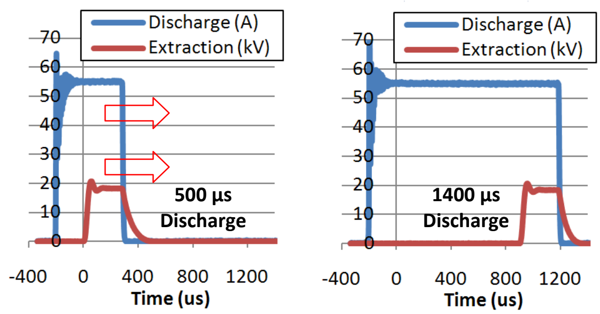

Figure 4: Extend the main discharge and keep extraction in the last 300 µs. Discharge current and extraction voltage shown.

As the discharge pulse length is extended the amount of power in the discharge is also increased. To offset this extra power the source air cooling flow rate must be increased to maintain the electrode temperatures. These are shown in table 1. The air cooling flow rate is used to control the anode temperature to 550°C ± 10 °C. The cathode cooling cannot be changed without modifying the thickness of a mica sheet component inside the ion source [3] so the cathode temperature slowly increases with increasing discharge duty cycle. The temperatures are allowed to stabilise at each duty cycle. As the discharge pulse length is extended the noise and ringing at the start of the discharge extends further into the discharge current pulse. To mitigate this, the Caesium oven temperature is also increased as shown in table1.

Table 1: Air cooling and Cs oven temperatures required for different discharge duty cycles. Electrode temperatures are also shown.

Duty Cycle (µs)	Power (W)	Air Flow (Lmin^{-1})	Cs Oven Temp (°C)	Anode Temp (°C)	Cathode Temp(°C)
500	110	7	169	552	467
800	176	11.5	169	555	490
1100	242	18	182	550	500
1400	308	24	192	557	510

Figure 5 shows the beam currents obtained for the different discharge current pulse lengths. As the discharge pulse length increases the beam current first rises then drops. Superimposed on figure 6 is the beam current for a long pulse extraction voltage. The beam current for the short extraction pulse at the end of the 1400 µs discharge is exactly the same as the corresponding portion of the long pulse extraction case; this confirms the results shown in figures 2 and 3. However the currents for shorter discharge duty cycles (500 µs, 800 µs and 1100 µs) are significantly greater. This suggests that increasing the discharge length before extraction decreases the beam current.

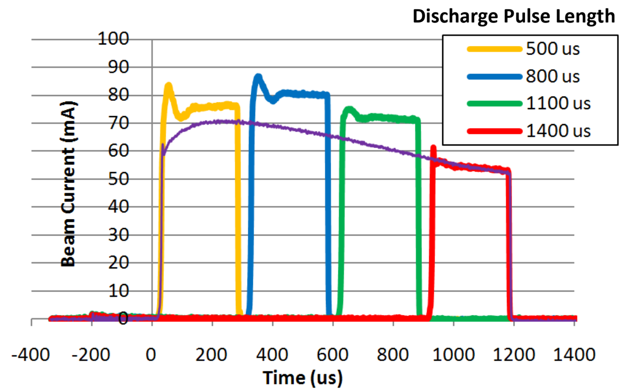

Figure 5: Beam currents for extending the main discharge whilst keeping extraction in the last 300 µs.

Extending the Discharge Before and After the Extract

Figure 6 illustrates developing the previous experiment further: for each discharge pulse length the extraction voltage pulse is moved in 300 µs steps until beam currents have been obtained for all combinations of discharge length and extraction position

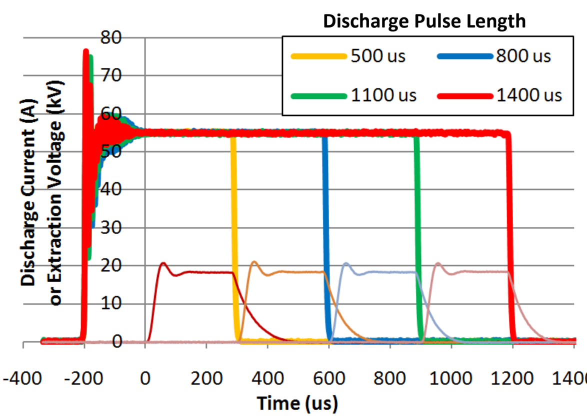

Figure 6: Extend the discharge current pulse length and move extracted beam to different positions.

The beam current pulses between 0 and 300 µs in figure 7 show the effect of increasing the length of the discharge beyond the end of the extraction voltage pulse. As the discharge pulse length is increased, first the beam current produced increases, then it decreases.

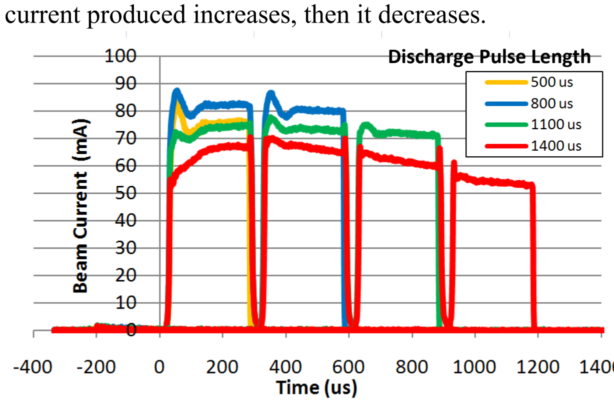

Figure 7: Beam currents for different dicharge lengths and extraction positions.

The different colours in figure 7 represent the different discharge pulse lengths. The overall profile of same colour current traces show what the longest beam current pulse would look like for each discharge length.

As the beam and discharge pulses get longer first beam current increases, then it starts to decrease and the droop becomes more pronounced.

Vary Hydrogen Gas Pulse

To investigate the cause of the beam current droop, the timing and amplitude of the drive voltage applied to the piezo-electric hydrogen gas valve is varied. Normally the drive voltage comes on 800 µs before the discharge and has an on time of 200 µs. Figure 8 shows the beam current for different hydrogen gas pulse timings.

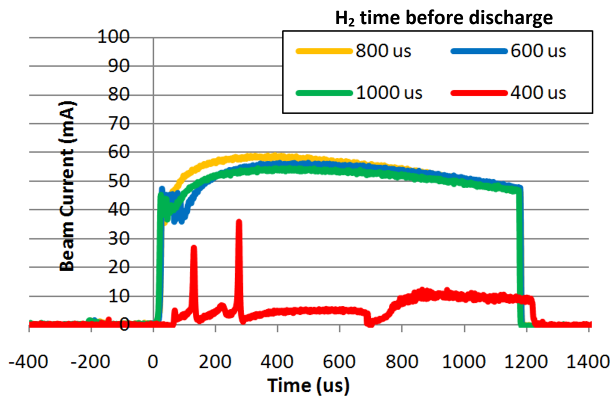

Figure 8: The effect moving the hydrogen pulse has on beam current.

When the hydrogen pulse is moved too close to the discharge, the discharge cannot strike properly (400 µs). Varying the hydrogen timing only has limited effect on the overall beam pulse shape. Similarly, increasing the amplitude of the drive pulse only has a small effect on beam current. Increasing the amount of hydrogen actually decreases the measured beam current slightly because of stripping losses as the beam is transported to the measurement toroid. Variation of the gas pulse cannot ameliorate the beam current droop for long pulses.

DISCUSSION

The length of discharge pulse dictates the maximum extractable beam current. The length and position of the extraction pulse merely samples the beam that is available to extract from the discharge at that point.

On first examination the result shown in figure 7 (between 0 and 300 µs) does not make sense: why should extending the discharge beyond the extraction region affect the current before it?

The answer might lie in the electrode surface temperature and the Cs equilibrium coverage. Previous transient thermal finite element modelling studies [4] have shown that the electrode surface temperatures increase by over 50 °C during the discharge pulse as shown in figure 9. After the pulse has finished the electrode surface temperatures cool until the next discharge pulse begins.

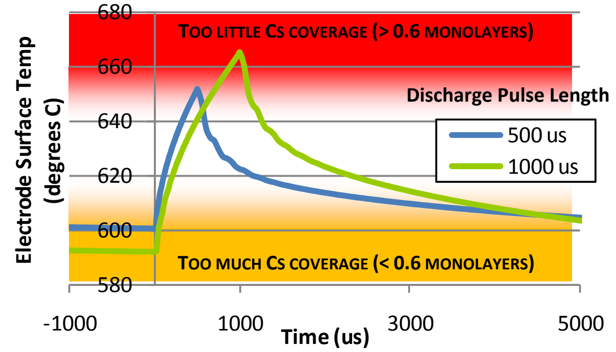

Figure 9: Electrode surface temperatures calculated by 3D finite element modelling.

Increasing the discharge pulse length increases the amount the electrode surface temperatures rise during the on period of the discharge pulse. The extra air cooling (table 1) can bring down the average temperature of the electrodes but it cannot mitigate this transient surface temperature rise. When the temperature rise becomes large enough the electrode surface temperatures go out of the optimum region for Cs coverage and H^- production. This causes the extractable beam current to droop at the start and end of the pulse.

FUTURE WORK

The effect of varying the repetition rate of the discharge needs to be studied, but if the droop is caused (as suggested) by electrode surface temperature rise, the only way to offset this is to increase the electrode surface area. Increasing the electrode surface area reduces the surface power density and reduces the transient temperature rise. This has been successfully achieved by Sherman et al. [5] by producing a x4 scaled source.

REFERENCES

[1] D.C. Faircloth et al, "The Front End Test Stand High Performance H^- Ion Source at RAL", Review of Scientific Instruments, Volume 81, Issue 2, (2010).

[2] D.C. Faircloth, M. O. Whitehead and T. Wood, "Practical Experience in Extending the Ion Source and Injection System H^- Ion Source Duty Cycle", Review of Scientific Instruments Volume 77, Number 3, (2006).

[3] D.C. Faircloth, J. W. G. Thomason, M. O. Whitehead, W. Lau and S. Yang. "Thermal Modelling of the ISIS H− Ion Source", Review of Scientific Instruments, Volume 75, Number 5, (2004).

[4] D.C. Faircloth and J.W.G. Thomason, "Extending the Duty Cycle of the ISIS H^- Ion Source, Thermal Considerations", Proceedings of EPAC04, TUPLT139, (2004).

[5] H. V. Smith and J. Sherman, "H^- and D^- scaling laws for Penning Surface-Plasma Sources", Review of Scientific Instruments, Vol 65 (1), pp. 123-128 (1994).