ISIS ION SOURCE OPERATIONAL EXPERIENCE

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Abstract

The ISIS ion source is a surface plasma ion source of the Penning type, and routinely produces 35 mA of H^- ions during a 200 μs pulse at 50 Hz for uninterrupted periods of up to 40 days. A new computer control system was installed in 1995, which, in addition to providing much tighter control of ion source parameters, has allowed these parameters to be logged every fifteen minutes and then averaged on a daily basis. A detailed analysis of these data from every ion source run on ISIS during the last five years shows the range of regimes under which operation is possible, but highlights the adverse effects that certain modes of operation may have. Evidence is provided that apparently small mechanical defects can have a marked impact on how an individual ion source behaves. Practical experience has determined the parameter changes necessary to maintain optimum performance. These typical changes are seen in the logged data and explained in terms of ion source physics. This design of ion source will be used on the RFQ test facility at Rutherford Appleton Laboratory (RAL), and an improved version may be viable for the European Spallation Source project.

1 INTRODUCTION

Previous papers have described the operation of the ISIS ion source at RAL [1] and the installation of its computer control and monitoring system [2]. A schematic diagram of the source is shown in figure 1.

A Penning discharge is struck in a mixture of hydrogen gas and caesium vapour by applying a pulsed (≈ 500 μs, 50 Hz) bias of ≈ –150 V to the cathode, which is electrically isolated from the other source components. H^+, H_2^+, and H_3^+ ions from the hydrogen discharge are backscattered from the cathode surfaces and can capture electrons to form H^- ions. The donation of electrons is greatly enhanced by adsorption of caesium onto the molybdenum cathode surface, which reduces its work function from 4.5 eV to 1.2 eV for an optimal surface density of caesium. These surface reactions are efficient for production of 10–100 eV H^- ions, but these would give too high an emittance in the extracted beam. Hence H^- ions from the cathode surface are physically obstructed from passing directly into the extraction aperture and must first undergo resonant charge exchange with slow (<1 eV) H atoms in the recess adjacent to the aperture. The slow H^- ions produced are extracted by a 17 kV potential applied to the extractor during the last ≈ 200 μs of the discharge pulse and then pass through a 90° sector magnet

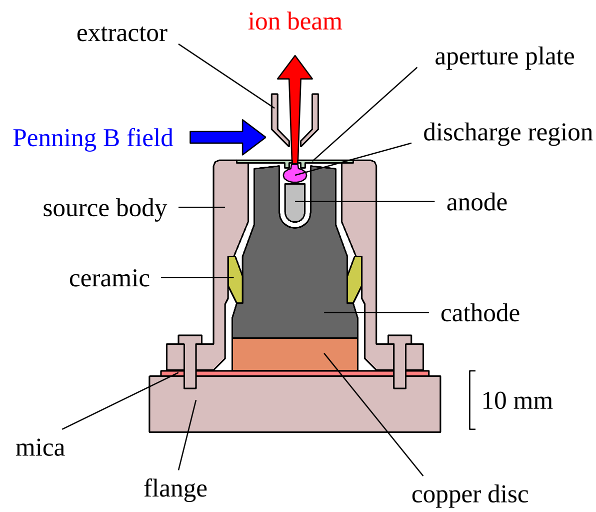

Figure 1: Schematic of the ISIS H^- ion source.

in order to separate out electrons extracted from the source. The magnet pole pieces are set into the sides of a stainless steel ‘cold box’, which is maintained at about –5 °C to condense excess caesium emitted from the source. The H^- ions then traverse a 665 kV DC medium gradient accelerating column to provide a high brightness 35 mA ion beam for the ISIS linac.

2 OPERATIONAL PARAMETERS

Over the last five years ≈ 60 ion sources have been run on ISIS. There are six operational ion source assemblies, which supply hydrogen via a pulsed piezo-electric gas valve and caesium from a boiler, as well as providing thermocouple monitoring of source component temperatures. Before use each source is fitted with a new cathode, aperture plate and ceramic. Nine source bodies, into which anodes are press fitted, are reused, with individual anodes being replaced when there is evidence that the thermal contact between the anode and source body is poor or that the anode has become unduly worn.

The computer control system, which operates over a fibre-optic link, allows discharge current (I_D), extract voltage, sector magnet current, gas pressure, anode temperature (T_A), cathode temperature (T_C), source body temperature (T_S), caesium boiler temperature (T_{Cs}), H_2 gas pulse length, discharge pulse length (τ_D), extract pulse length and ion beam current (I_B) to be logged every fifteen minutes and then averaged on a daily basis. The database derived from these parameters has been analysed to investigate the behaviour of the operational ISIS ion source. It should be noted that the source is always tuned to give $I_B \approx 35$ mA; other operating modes could probably be established for different ion beam currents. Many interesting correlations have been found between the logged parameters, the most significant of which are presented in figure 2.

In order to reduce the ≈ 1000 data points that would otherwise appear in each part of figure 2, data have been averaged in suitable intervals. For instance in figure 2a) 5 A intervals in I_D have been chosen to give reasonable statistics, with bars representing one standard deviation of the values being averaged. In each case a weighted least squares fit has been applied to produce the dashed line and emphasise the trend in the data.

Figure 2a) shows the interdependence of I_D and τ_D. The source is normally set up at a particular value of T_C, established by expedience, and then T_C is maintained throughout the run. This ensures that the amount of caesium on the cathode surfaces remains optimal. It can be seen from figure 2d) that if T_C is raised increased thermal desorption of caesium must be overcome by increasing T_{Cs} and hence the flux of caesium onto the cathode surfaces. The value of T_C is determined by the total power fed into the discharge, explaining why an increase in I_D is accompanied by a decrease in τ_D. However, it should be noted from figure 2b) that an operating regime with high I_D requires higher T_{Cs}. This may not be desirable, as increased caesium flux can lead to excessive extractor currents as well as possible contamination of the accelerator column. These effects may not necessarily affect source lifetime or performance, but often lead to an increased incidence of extract and column breakdowns which may damage other equipment or interrupt ISIS running.

The data analysis reveals that the difference between T_C and T_A is the only parameter which appears to have any marked effect on source lifetime, as shown in figure 2c). Clearly, given the evidence of figure 2d) and the preceding discussion, it is preferable to achieve high $T_C - T_A$ by maintaining low T_A rather than high T_C. T_A is usually determined by the thermal conductivity between the anode and source body (which is air cooled internally), which in turn depends upon the interference fit between these two components. This demonstrates the vital importance of quality control during the assembly of ion sources and the manufacture of source components.

Practical experience has shown that, during the lifetime of a source, I_B can be tuned most effectively by altering the values of I_D and τ_D. Generally an increase in I_B is obtained by moving from low to high I_D and compensating for the change in T_C with τ_D as in figure 2a). Figure 2e) shows that I_D must be increased gradually with time in order to maintain an optimal I_B.

Figure 2 represents the entire database, with no data having been excluded. Trends in the data are broadly similar when individual ion source bodies and assemblies

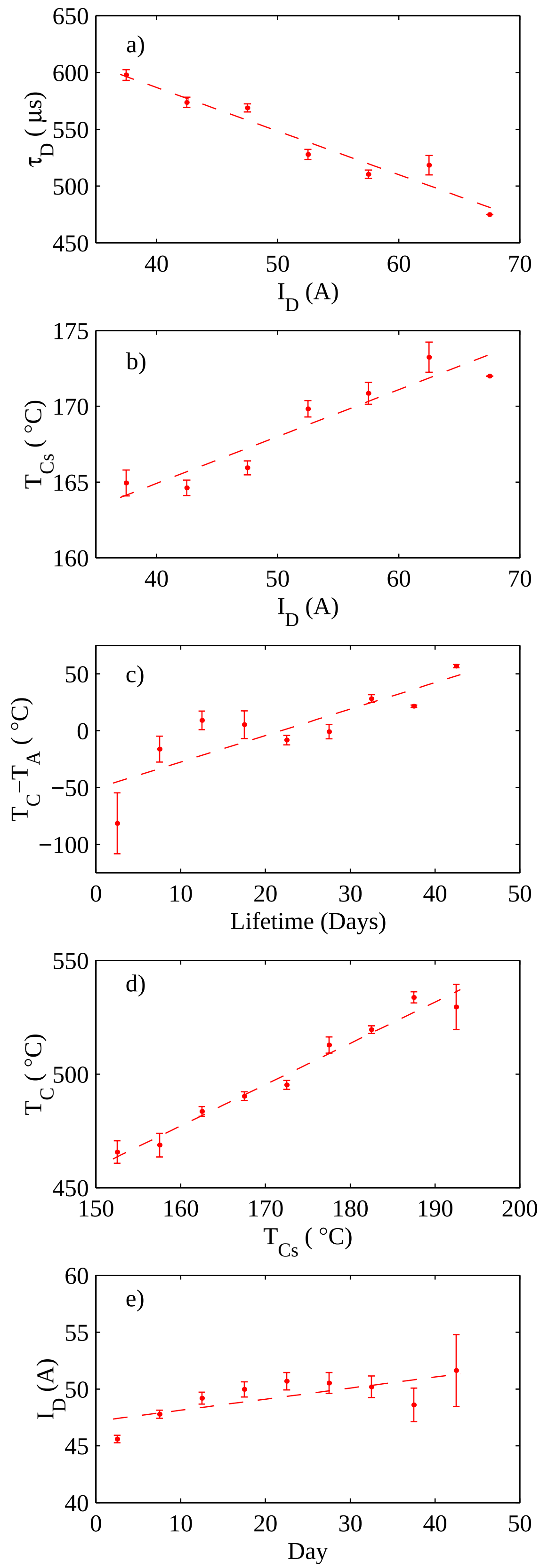

Figure 2: Operational ion source parameters.

are considered, but this analysis is beyond the intended scope of this paper.

3 QUALITY CONTROL

Recent experience has shown that apparently small changes introduced in the manufacture of ion source components can cause unexpected problems. Normal cathode edges are specified as having 0.15 mm radii. However, one batch of twenty cathodes procured through outside manufacture was found to have edges much sharper than this.

Figure 3a) shows oscilloscope traces of I_D and extractor current (I_E), obtained from the ion source via a 0-33 MHz fibre-optic analogue link, and of I_B. This is a typical example of running with a properly manufactured cathode. It can be seen that I_D (55 A) and τ_D (520 µs) are close to the centre of the range of values shown in figure 2a). Noise is evident during the first ≈ 280 µs of the discharge current pulse, but is damped because there is a sufficient density of caesium on the cathode surfaces. The mechanism for this phenomenon is discussed in [3]. Noise does not intrude into the extract pulse or the ion beam pulse, where I_B = 35 mA. The initial spike in I_E represents the charging current for the extractor and cold box, but the demand rapidly settles to a level of ≈ 0.25 A.

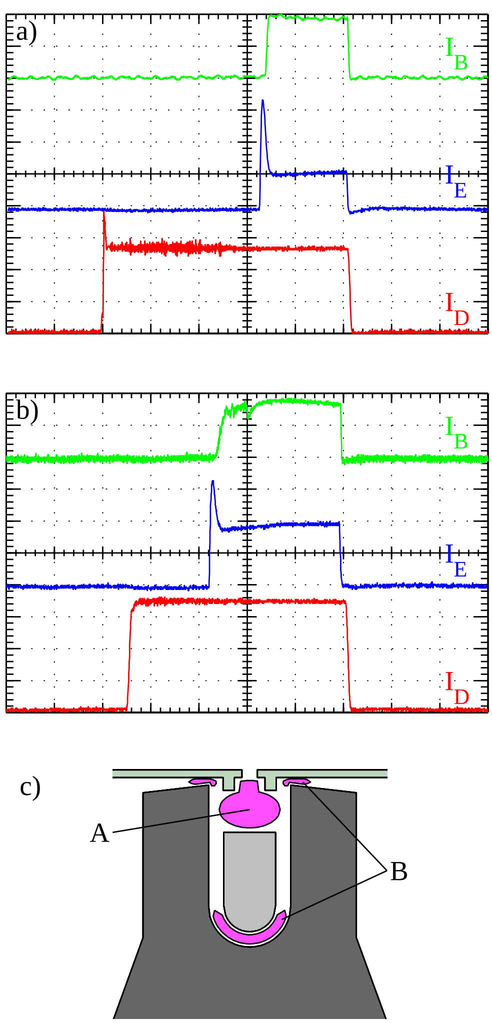

Figure 3: Oscilloscope traces (100µs/div) for a) typical running and b) abnormal running. c) Detail of the top of the cathode showing normal (A) and extraneous (B) discharge regions.

Running with a cathode with sharp edges results in the oscilloscope traces of figure 3b). Here I_D (68 A) and τ_D (450 µs) are at the extreme of the operating range. This is attributed to additional discharge current being required to feed extraneous discharges induced by the enhancement of electric field gradients at the sharp edges. Careful examination of burn marks on the used source components reveals these discharges to have been as indicated in figure 3c). With such a high I_D, T_{Cs} must also be high, as in figure 2b), and the consequent large flux of caesium into the extraction gap results in an excessively high value of I_E (> 0.5 A) and an increased risk of extract breakdown. In addition it has been necessary to increase the extract pulse width to compensate for the smaller magnitude of I_B (≈ 32 mA), further increasing the demand on the extract power supply. Even with high T_{Cs} there is not sufficient caesium on the cathode surfaces to damp noise in the discharge effectively, and so noise now intrudes into the first ≈ 80 µs of the ion beam pulse. During the lifetime of this source large amounts of caesium were condensed on the magnet pole pieces housed in the cold box. While this caused no immediate problem, in a subsequent run some of this caesium was liberated by H^- ions striking the pole pieces after a sudden increase in source output. This resulted in contamination of the accelerator column and a spate of breakdowns.

Obviously cathodes with sharp edges have serious disadvantages, and the remaining cathodes from the offending batch were modified to meet the original design specification.

4 CONCLUSIONS

The results presented in sections 2 and 3 indicate favourable operating regimes for the ISIS H^- ion source, and also emphasise the importance of maintaining high standards in manufacture and assembly. An identical ion source will be used on the RFQ test facility at Rutherford Appleton Laboratory [4], and an enhanced version may be developed for the European Spallation Source project.

REFERENCES

[1] R.Sidlow *et al.*, EPAC 96, THP084L.
[2] M. Perkins *et al.*, EPAC 96, TUP081L.
[3] G.E. Derevyankin and V.G. Dudnikov, Proceedings of the 3rd international symposium on the production and neutralization of negative ions and beams, BNL, 1983, AIP Conf. Proc. No. 111, pp 376-396, 1984.
[4] D.J.S. Findlay *et al.*, EPAC2000, THP4A03.