Performance of the Penning H⁻ Ion Source at ISIS

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Abstract

The linac injector to the ISIS rapid cycling synchrotron employs a Dudnikov type Penning H^- ion source. Operationally the source delivers a pulsed current of 20 to 40 mA, at 50 Hz pulse repetition rate and pulse lengths up to 500 μs. A description of the source is given together with an account of its development and operational performance.

1. INTRODUCTION

The original construction and development of the ISIS Injector H^- ion source has been described earlier [1] and the source has now been in regular operation since 1985. The source is based on the design by Dudnikov [2], later developed by Allison [3], and with many features of the magnetron source at Fermilab [4] incorporated in its detailed construction.

The principal components of the source are illustrated in Fig 1. The arc discharge region is defined by a 10 x 2 mm slot in the anode and by the 5 mm gap between the two cathode surfaces. Beam is extracted at right angles to the discharge through another anode slot, which is capped by a thin plate pierced by a 10 x 0.6 mm beam extraction slit. These components are assembled into the source body with the cathode located by a machinable ceramic insulator. The ion source body contains air ducts to provide cooling and the cathode is conduction cooled through a 0.3 mm thick mica sheet to a water cooled base-plate.

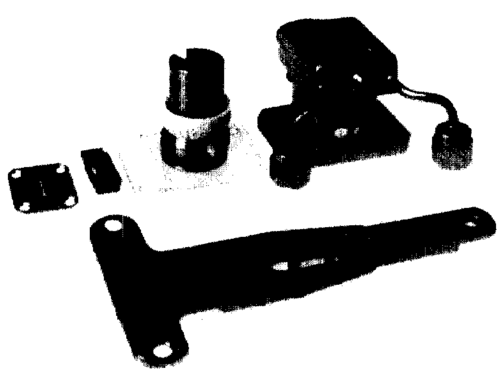

Fig 1. Ion source components. l to r: extraction slit plate; anode; cathode; ion source body; & below: extraction electrode.

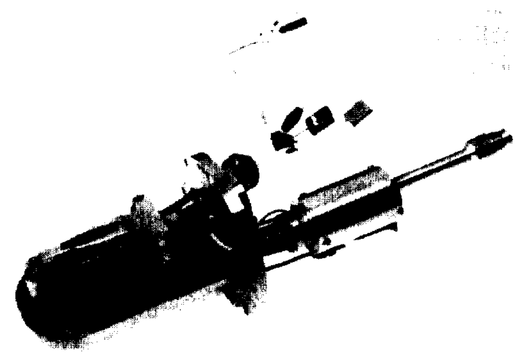

Fig 2. Ion source assembly.

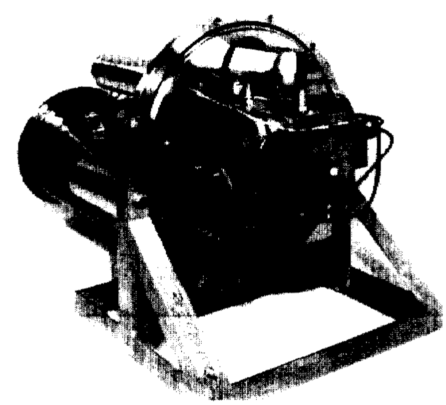

Fig 3. Ion source magnet assembly.

Fig 2 shows the source assembly with the extraction electrode mounted to give a 2.1 mm extraction gap. The source is fed with hydrogen gas via a pulsed piezo-electric valve, with the flow regulated by stabilising the pressure in the ion source vacuum enclosure. Caesium vapour is also fed to the source from a temperature regulated boiler loaded with a 2 gm caesium ampoule.

The extracted H^- beam is focused by a 90° gradient bending magnet with extensions to the pole-pieces to provide the field for the ion source Penning discharge. Gaps in the magnetic circuit allow the pole-pieces to be held at the extraction potential, as also is a surrounding refrigerated cold box designed to capture excess caesium from the source. The magnet assembly with installed ion source is shown in Fig 3. This assembly is mounted on the high voltage terminal of a 665 keV dc accelerating column at the input to the ISIS linac.

2. SOURCE OPERATION

In general it takes about an hour from start-up to establish suitable source operating conditions. The caesium boiler is set to about 190° C and the source is warmed up by a low current dc arc power supply until there is an abrupt fall in the arc impedance, when a pulsed arc supply is then able to establish the high current arc pulses. Usually it is then possible to operate with the dc arc power supply switched off, which is found to be a necessary requirement if maximum H^- beam current is to be achieved, and the caesium boiler temperature is reduced to about 180° C. The pulsed extraction voltage is normally operated during the source warm-up period to keep the extraction gap conditioned.

The source is optimised by balancing the air cooling of the source body against the arc power, to give a cathode temperature at which maximum beam current is produced. The hydrogen gas flow is adjusted to maintain a stable arc.

Over the life of a source the operating parameters are periodically adjusted for optimum performance, but there is still a steady decline in output associated with the erosion of the anode. The ISIS beam intensity is maintained by increasing the beam pulse length but eventually the source has to be replaced. Typical source operating parameters are given in Table I and typical pulse waveforms shown in Fig 4.

TABLE I
Typical Source Operating Parameters

Arc current	50 A
pulse width	450 μs
repetition rate	50 Hz
Extraction voltage	18 kV
pulse width	150-300 μs
Temperature of cathode	520-560° C
anode	600-800° C
Cs boiler	175-180° C
H^- pulsed beam at 665 keV	40-20 mA
Normalised emittance at 665 keV - 30mA beam	
Horizontal	2.1π umr
Vertical	3.0π umr

3. SOURCE DEVELOPMENT

Early experience in the operation of the ion source was troubled by unreliable and variable behaviour and considerable work was necessary to achieve a performance acceptable to the operational requirements of ISIS. One difficulty in the source development has been the failure to achieve as satisfactory a performance on the ion source test rig as on the accelerator, so most of the development has been carried out on the operational source. This has restricted the occasions when changes could be made and also the magnitude of the change at any stage.

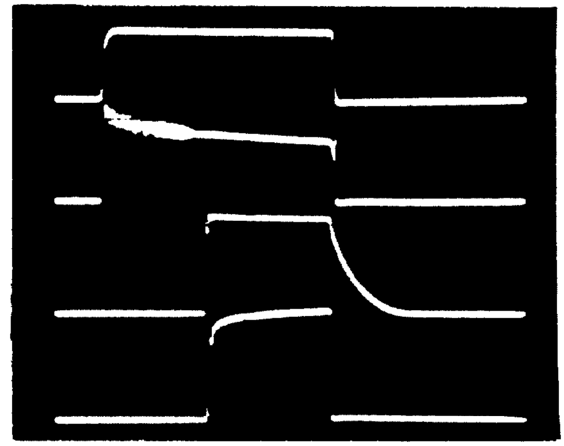

Fig 4. Typical source pulsed signals. From top: Arc current, 48 A, 450 μs; Arc voltage, 70 V; Extraction voltage, 18 kV; Beam at 665 keV, 28 mA, 240 μs.

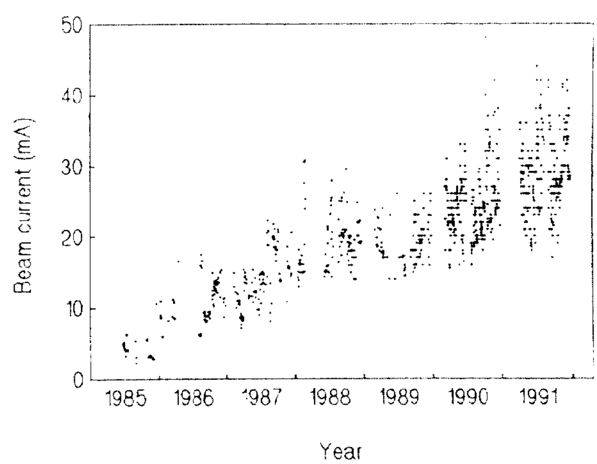

Fig 5. Recorded H^- current from operational sources.

A record of measured beam current at 665 keV taken during ISIS operation is given in Fig 5. In general, the steady improvement in operational ion source current shown has just managed to keep pace with the ability of the synchrotron to handle higher intensity beams.

The performance of individual sources over the past year is shown in Fig 6. Removal of a source before the beam current had fallen to below 20 mA was normally for operational reasons other than source failure.

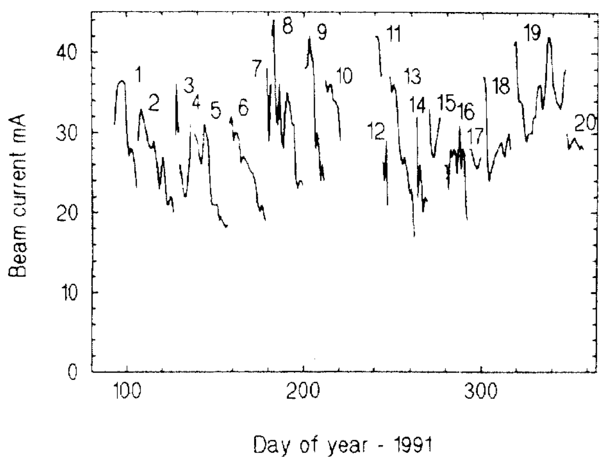

Fig 6. H^- current from recent operational sources.

Greater reliability of the source has been achieved mainly by improving the detailed engineering to eliminate weaknesses as they have become apparent. Examples are the introduction of water cooling on the pulsed hydrogen gas valve, control over cooling of the source body, elimination of an isolation valve between caesium boiler and source, improved layout of electrical feeds to the source, use of aluminium nitride to insulate the cathode monitoring thermocouple and adoption of a systematic refurbishing procedure to achieve better quality control.

Improvements to the ion source power supplies have also been important, particularly in achieving the higher beam intensities. The current rating of the extraction power supply has been increased to 150 mA, in order to handle the loading due to a spurious discharge which can be seen between the source body and the poles of the 90° magnet. The magnitude of the loading is a function of vacuum pressure and sets a limit to the width of the extraction slit and hence to the extracted beam current.

The maximum voltage from the arc power supply has been increased to 315 V, to achieve reliable striking of the arc once the dc arc power supply has been switched off. A new power supply of even higher voltage rating is being designed.

Installation of a filter in the arc supply leads has eliminated serious interference to the electronic equipment due to an oscillation of the arc discharge. This usually starts at the front end of the arc pulse, as seen in Fig 4, and increases in duration as the source ages.

An attempt to operate the source without caesium was made by replacing the active faces of the molybdenum cathode by lanthanum hexaboride. Although a high current, low impedance arc was easily obtained, only a very low H^- beam could be extracted. There was no improvement with the addition of caesium.

The use of tantalum in place of molybdenum for the source components has been tried in the hope of increasing the source operating life. A stable high current arc could not be established using a tantalum cathode and results with a tantalum anode have been inconclusive. In the only case in which a satisfactory beam was obtained the tantalum anode was found to have become severely distorted after only a few days of operation.

Recently a modification has been tried, suggested by work at Los Alamos [5], which aims to reduce erosion of the anode through better cooling. The geometry of the anode is unchanged but the two vulnerable anode ribs are made part of the extraction slit plate to provide a better thermal conduction path. Such a source, No 19 in Fig 6, showed very little anode erosion or reduction in output when it was routinely replaced after 28 days operation. The full extent of the improvement in source life will not be known until the next ISIS operational period.

4. CONCLUSION

Continuous development has enabled the H^- ion source to keep pace with the steadily increasing demands of the ISIS synchrotron. An operating current of over 30 mA can now be sustained for an ion source life-time which exceeds 28 days.

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