SEPARATING THE PENNING AND ANALYZING FIELDS IN THE ISIS H^- ION SOURCE

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Abstract

The development of H^- ion sources with performances exceeding those achieved today is a key requirement for the next generation of high power proton accelerators. The ion source development program at ISIS is now well established. To allow different ion source designs to be fully tested, the ability to vary the Penning field is required. Until now the Penning field has been generated by the same magnetic circuit that creates the analyzing field, giving no practical way of altering the Penning field alone. This paper describes the infrastructure changes required to allow the Penning field to be independently varied. The effect the Penning field has on beam current, emittance and discharge stability are discussed.

INTRODUCTION

The ISIS H^- ion source is a Penning Surface Plasma Source (SPS). Its construction and operation has been described in detail in a previous paper [1]. In recent years there has been a significant research and development effort to extend the pulse length and beam current to meet the requirements of the next generation of particle accelerators. This work has involved theoretical computer modelling [2][3], and experimental work on a specially built test stand [4]. Experimental work has studied the effect of varying different parameters such as H_2 gas flow, caesium boiler temperature, cooling and source geometry changes. The only parameter that could not be easily varied is the Penning Field.

The Penning field is a transverse magnetic field applied across the discharge region. It causes electrons in the discharge to spiral and increase the efficiency of H^- production.

HARDWARE MODIFICATIONS

Original Setup

The Penning field was produced by pole tip extensions on the top of the analyzing magnet. The analyzing magnet is a 90º sector magnet used to separate the H^- ions from the other negative ion species which are also extracted from the source. The analyzing field must be matched to the energy of the extracted H^- ions; hence the Penning field could not easily be varied. Only by changing the size of the pole tip extensions could the Penning field be altered. This involved a very time consuming rebuild of the ion source vacuum vessel.

New Penning Magnetic Circuit

To allow full control of the Penning magnetic field a separate magnetic circuit consisting of coil, yoke and pole pieces were added to the source vacuum vessel (Fig. 1).

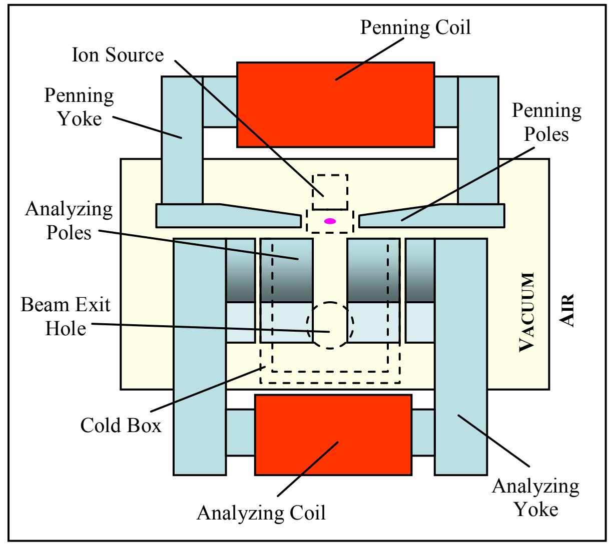

Figure 1: Schematic of the analyzing and Penning magnetic circuits.

The source vacuum vessel has been previously redesigned to accommodate a top-loading ion source and spare feed-throughs were added at the time to allow the new Penning yoke to be easily added. The Penning coil sits outside the vacuum vessel.

Figure 2: Close-up of the ion source between the Penning pole pieces.

Coupled Magnetic Circuits

The analyzing magnetic circuit and the Penning magnetic circuit are in close proximity, so there is significant coupling between the two. When the Penning field is low a significant proportion of the flux in the analyzing magnetic circuit couples into the Penning circuit. Hence much higher analyzing coil currents are required when the Penning coil current is low. For a 17kV extract potential the required analyzing coil currents for different Penning coil currents are shown in Fig. 3.

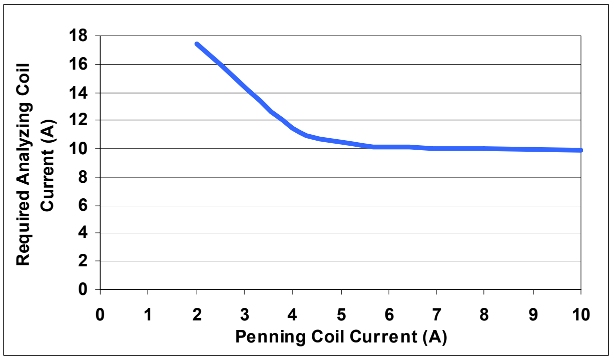

Figure 3: The analyzing coil current required for different Penning coil currents (17kV extract potential).

Magnetic Measurements

Using a Hall probe the magnetic field between the Penning and sector magnet pole tips is measured. For a 17keV H^- beam, an analyzing field of 0.236T is required to get the beam to bend through 90º. Fig. 4 shows the transverse magnetic field around the arc of the analyzing magnet. The top of the extraction electrodes are at 0º. The ion source discharge region is between -6º and -14º. The thick dotted line shows the magnetic field in the original arrangement (with fixed Penning pole pieces attached to the top of the analyzing magnet poles). The other curves show how the field varies for different Penning coil currents. The sector magnet current has to be varied to keep the sector magnet field at a constant 0.236T for each Penning coil current.

The overall result is the Penning field in the ion source discharge region can be varied whilst the field in the sector magnet is kept constant.

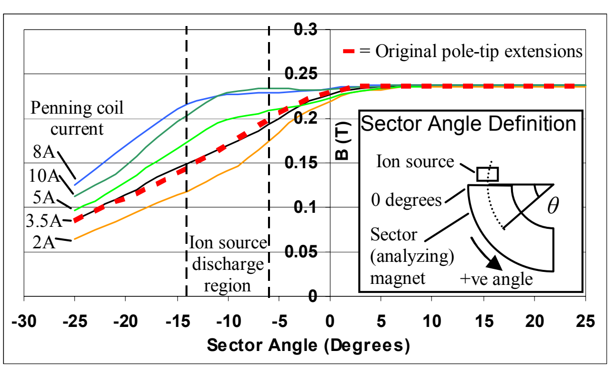

Figure 4: Magnetic survey data.

RESULTS

Set-up

To study the effect of varying the Penning field the source was run with the normal operating conditions shown below:

Table 1: Normal operating conditions.

Parameter	**Value**
Discharge current	50A
Discharge Length	800µs
Rep. Rate	50Hz
Extract Volts	17kV
Extract pulse length	175µs
Caesium boiler temperature	164ºC
Anode thermocouple	466ºC
Cathode thermocouple	482ºC

Discharge Stability

The initial start-up of the source involves heating the electrodes to temperature using a DC discharge current before switching to a pulsed current. The transition to pulsed mode can be achieved quicker when high Penning coil currents of 8A or more are applied.

When the source is running in pulsed mode the discharge becomes unstable for Penning current of less than 4A. Higher Penning currents give a very stable and reliable discharge.

Effect on Wave-Shape

Fig. 5 shows the ion source wave shapes for a 4A Penning coil current. The noise on the front of the discharge current pulse can be seen to extend about 150µs into the pulse. This noise limits the maximum length of the extract pulse because the noise will be seen on the beam current.

As the Penning coil current is increased the noise on the front of the discharge current pulse extends. Fig. 6 shows the wave shapes obtained for a 10A Penning coil current. The noise on the beam current now extends to about 300µs.

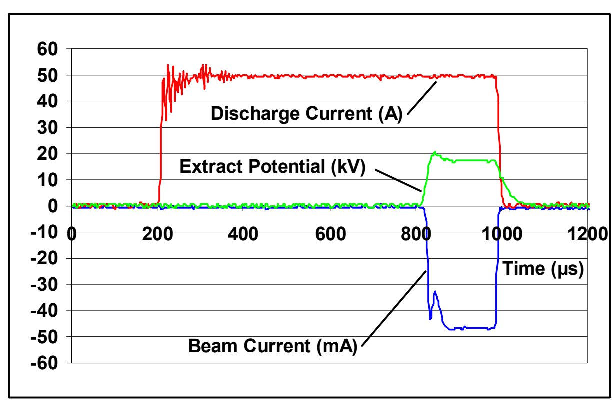

Figure 5: Scope traces for 4A Penning coil current.

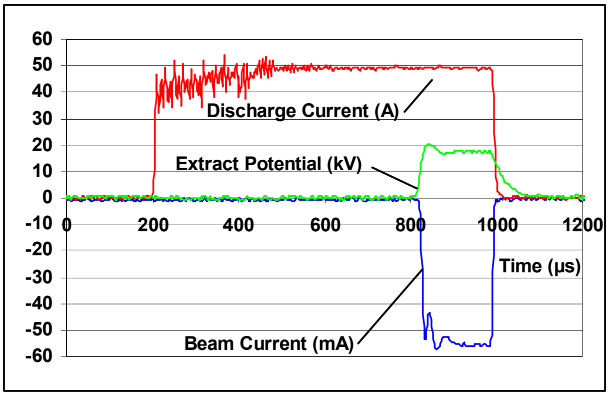

Figure 6: Scope traces for 10A Penning coil current.

Beam Current

Fig. 7 shows the variation in H^- beam current as measured using a toroidal current transformer. The output beam current increases as the Penning field increases. Beyond 6A Penning coil current there is no further increase in beam current.

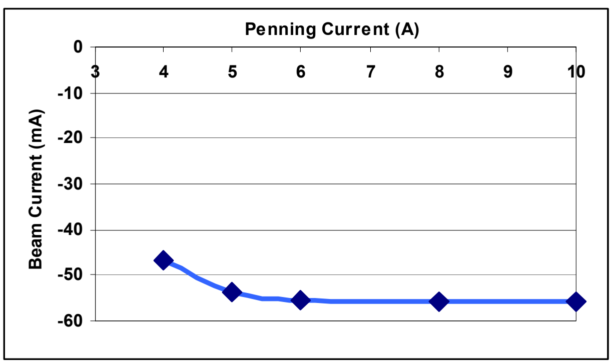

Figure 7: Variation of output beam current with Penning current.

Beam Emittance

The beam emittance is measured at different Penning coil currents. Two (horizontal and vertical) slit and cup emittance scanners are used to measure the emittance.

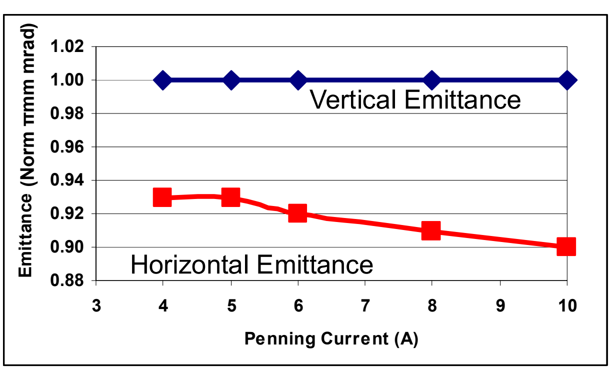

Figure 8: Variation of beam emittance with Penning coil current.

The normalized emittance versus Penning coil current is shown in Fig 8. The Penning field has very little effect on overall beam emittance. The horizontal emittance shows a slight decrease for high Penning fields.

DISCUSSION

Separating the Penning field from the analyzing field has several advantages, it allows many different settings to be tested that would previously be extraordinarily time consuming. It allows different extract voltages to be tested whist keeping the Penning field constant.

Using a high Penning field, tests have shown that the time taken to start a source can be greatly decreased. The high Penning field increases the heating efficiency of the discharge current and speeds up initial electrode surface Caesiation.

For the conditions shown in Table 1there is an optimum Penning coil current of about 6A, below this value the output current decreases and the discharge becomes unstable, above this value excessive noise appears on the front of the discharge pulse. Extraction cannot occur in the noisy region of the discharge pulse, so the maximum achievable output beam pulse length is reduced for high Penning Fields.

Varying the Penning field appears to have no detrimental effect on emittance. The scanners are about 300mm downstream from the main 35kV accelerating gap, so there is significant emittance growth due to space charge before the measurement point, hence any small changes in emittance may be masked.

CONCLUSIONS

The separate Penning field allows a greater degree of control over the source. Stable discharges can be achieved for a wide range of experimental conditions. It facilitates the study of different source designs and the move to operation at higher beam currents and longer duty cycles.

ACKNOWLEDGEMENTS

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