The ISIS Penning H^- SPS and Diagnostic Developments at RAL

D.C. Faircloth[1], A.P. Letchford[1], J. Pozimski[1+2], M.O. Whitehead[1], T. Wood[1], S. Jolly[2], P. Savage[2], M. Haigh[3], J. Morrison[3], I. Yew[3], G. Doucas[3]

1. ISIS, Rutherford Appleton Laboratory, Oxfordshire, UK
2. Imperial College, London, UK
3. Oxford University, UK

Abstract. This paper covers the recent work carried out at the Rutherford Appleton Laboratory (RAL) on the ISIS Ion Source Development Rig (ISDR). The development of a retarding potential energy analyzer is described and a measured energy spread of 17.6 eV ± 1.5 eV from the ion source is reported. Variation in energy spread versus discharge current is shown. The development of a pepperpot emittance scanner to study emittance variation along the beam axis is discussed.

Keywords: Penning H^- Surface Plasma Negative Ion Source, Retarding Potential Energy Analyzer, Pepperpot emittance measurement.
PACS:

INTRODUCTION

The ISIS Penning H^- Surface Plasma Source (SPS) development program at RAL has made great progress in the last 5 years. The Ion Source Development Rig (ISDR) has allowed ion sources to be developed and tested without compromising the operation of ISIS.

A new Front End Test Stand (FETS) is being constructed at RAL [1]. This will form the front end of future High Power Proton Accelerators (HPPA) required for ISIS MW upgrades and contribute to the UK design effort for Neutrino factory drivers. The FETS beam current and pulse length requirements have already largely been met: the current increased from 35mA to 70mA [1] and pulse length increased from 200µs to 1.5ms [2,3]. Attention now turns to the beam emittance. An accurate understanding of beam quality is essential for designing the next stage of a beam transport system for the FETS project.

To fully characterize the beam, an energy analyzer has been constructed and tested with all the main source parameters varied. A pepperpot emittance measurement device is being developed. This will allow studies of emittance variation along the beam axis. It will also provide emittance measurements required for the design of the LEBT in the Front End Test Stand.

The Ion Source

The basic construction of the ISIS ion source is shown in Figure 1. A low pressure pulsed Hydrogen discharge is generated in the discharge region with a Penning transverse magnetic field and a 50A discharge current. Gaseous hydrogen and Cesium vapor are fed into the discharge through a hollow anode.

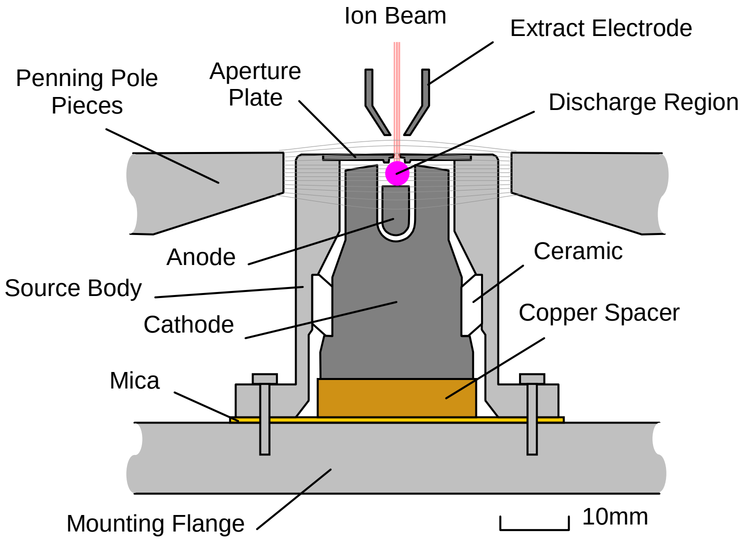

FIGURE 1. Construction of the ISIS Penning H^- SPS

ENERGY ANALYZER

Construction

The energy analyzer used is of the retarding field type - the beam is passed through a potential barrier, and the energy spectrum is deduced from measurements of the beam transmission as a function of barrier potential. The analyzer (Fig. 2) consists of several coaxial disc-shaped electrodes supported by ceramic posts, with apertures on the analyzer axis to allow passage of the beam.

The electrodes *b*, *c*, *e*, and *f*, are positioned symmetrically on either side of the retarding electrode *d*, and form a lens system. Electrodes *c*, *d* and *e* are connected to the negative terminal of a bipolar 150 V bias supply, the positive terminal of which is connected to the HT platform. Ions enter the analyzer with energies around the platform potential, so by changing the bias voltage then the potential at the retarding electrode can be varied over the range of ion energies, between complete transmission and complete attenuation of the beam.

Electrodes *b* and *c* focus the beam to a point in the centre of the aperture of *d*. This focusing is necessary because the retarding potential varies across the aperture, and so a dispersed beam of ions would see a large range of potentials; the resolution required of the analyzer is thus only achievable by focusing the beam. Electrodes *e* and *f* recollimate the beam after it has passed through the retarding electrode, and allow the measurement apparatus to operate at ground potential.

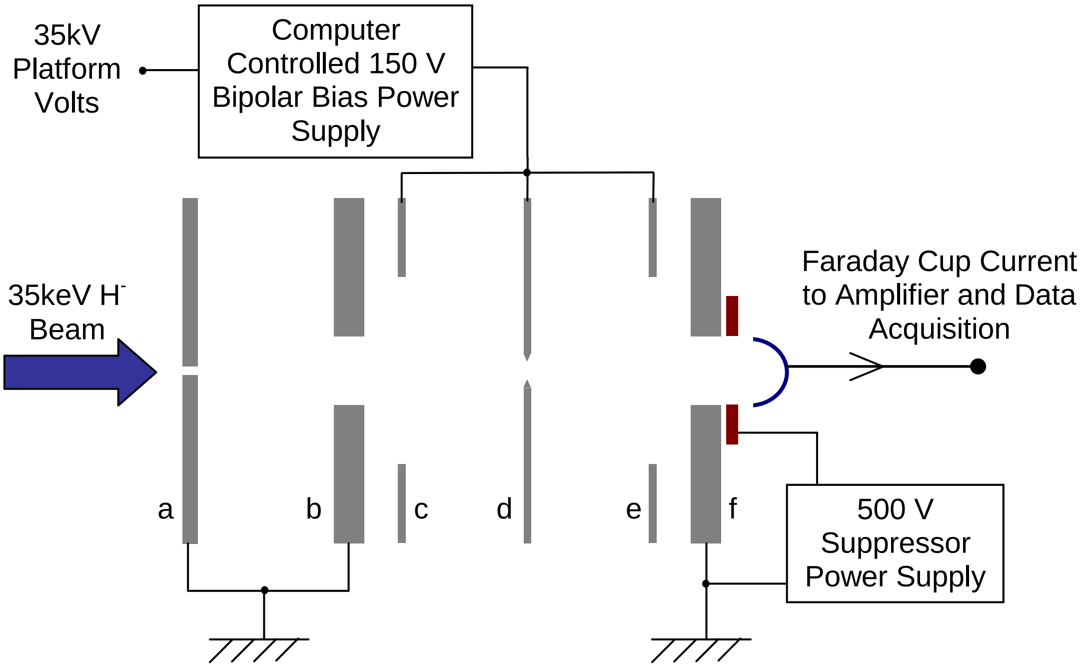

FIGURE 2. Construction of the retarding potential energy analyzer.

The optimum geometry for the focusing and retarding electrodes in this type of analyzer was calculated using 3D modeling software. The transmitted beam is collected on a Faraday cup placed after the last electrode, and the current on the cup is measured by a current preamplifier. A 500V suppression voltage deflects back any secondary electrons emitted from the cup. Electrode *a* restricts the amount of beam entering the analyzer, so that it is not swamped. Figure 3 shows the assembled energy analyzer.

FIGURE 3. The assembled retarding potential energy analyzer.

Operation

The analyzer has a finite resolution, since the energy which an ion must have to be transmitted through the analyzer at a given potential, is a function of the angle at which it approaches the retarding electrode. This is because the proportion of an ion's energy associated with motion along the analyzer axis is dependent upon its approach angle. This effect is parameterized by the instrument function $f\,(E + eV_{\mathrm{b}})$, which gives the proportion of ions with energies E in excess of the platform potential, which are transmitted through the analyzer with the bias voltage set to V_{b}. This function was calculated in the 3D modeling work; it contains a significant offset because the magnitude of the potential in the centre of the retarding aperture is less than that on the electrode surface. The measured current I_{o} is given by:

$$I_{\mathrm{o}} = -e\int_0^{\infty} f\,(E + eV_{\mathrm{b}})n(E)dE \qquad (1)$$

where $n(E)dE$ is the number of ions with energies in the range $(E, E+dE)$ passing through the analyzer each second. The analyzer is positioned to examine the core of the ion beam; the function $n(E)$ should therefore be proportional to the energy spectrum of this part of the beam. Equation (1) may be rewritten in terms of the resolution function $r\,(E+eV_{\mathrm{b}})$:

$$\frac{dI_{\mathrm{o}}}{dV_{\mathrm{b}}} = -e\int_0^{\infty} r(E + eV_{\mathrm{b}})n(E)dE \qquad (2)$$

where: $r(E + eV_{\mathrm{b}}) = \dfrac{d}{dV_{\mathrm{b}}} f\,(E + eV_{\mathrm{b}})$.

Because the instrument function varies from unity to zero over only a few eV, equation (2) provides the most convenient means to deduce $n(E)$ from measured values of I_{o}.

Energy Analyzer Results

Figure 4 shows the transmission curve for the ion source at normal operating conditions. The energy spread is 17.6 eV ±1.5 eV.

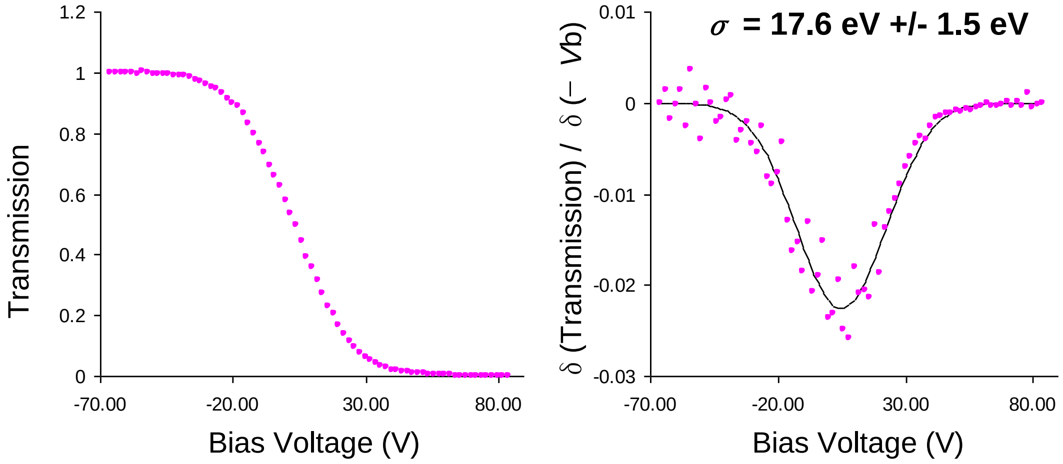

FIGURE 4. The ion source energy analyzer transmission curve and the calculated energy spectrum for a 50A discharge current.

The extraction voltage and beam energy were varied and the beam energy spectrum was measured but was not found to vary significantly. When the discharge current was altered a measurable variation in beam energy spectrum was observed. Figure 5 shows the variation of energy spectrum with discharge current. The spectrum width approximately doubles when the discharge current is doubled.

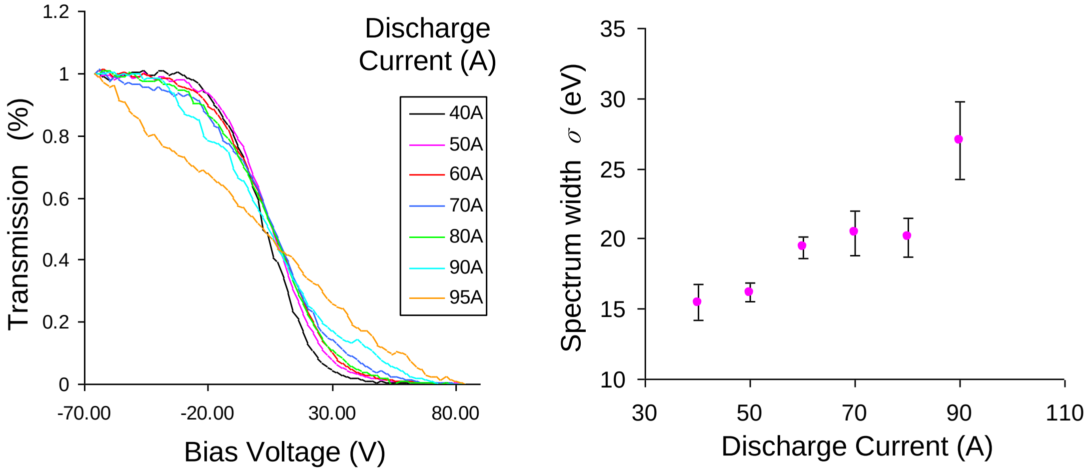

FIGURE 5. The ion source energy analyzer transmission curves for different discharge currents and calculated energy spectrum versus discharge current.

PEPPERPOT EMITTANCE MEASUREMENT

The pepperpot consists of an intercepting screen, a scintillating imaging screen, a high-speed CCD camera and associated support structures: the assembled system is shown in Figure 6.

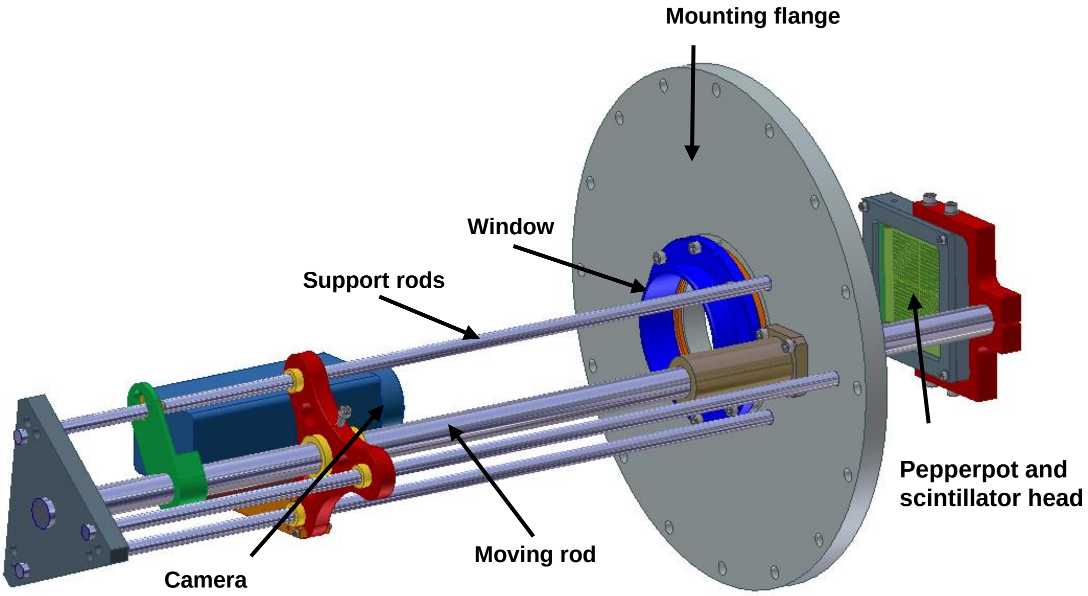

FIGURE 6. Isometric view of the pepperpot emittance measurement device designed to fit on the ISDR.

The intercepting screen is a 25 x 25 array of 100 μm diameter holes, on a 3 mm pitch, laser-drilled into a 0.3 mm-thick tungsten sheet. This is mounted to a 10 mm thick copper block, through which 2 mm diameter holes are drilled at an identical pitch to allow the ion beamlets to pass. The scintillator material is mounted 3 mm from the copper block.

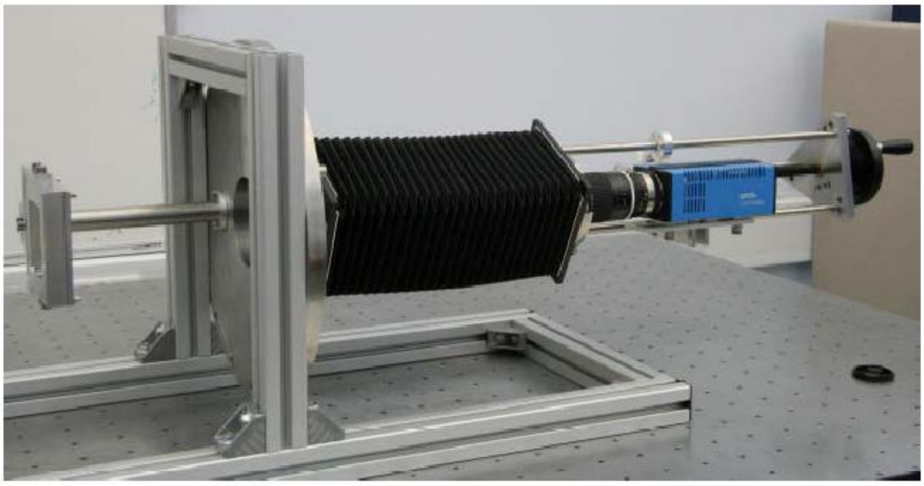

FIGURE 7: The Pepperpot emittance measurement device, prior to installation onto the ion source (shown mounted into aluminum test frame).

The light spots produced by the beamlets impacting on the scintillator screen are imaged using a PCO 2000 high speed camera with a 2048 x 2048 monochrome sensor and a Nikon 105 mm f/2.8 macro-lens: mounted 700 mm from the scintillator screen, this provides a resolution of 45 μm per pixel and an angular resolution of 3.5 mrad. The camera is mounted to an aluminum support plate and is tilted with respect to the phosphor screen by an angle of 60 mrad to minimize smear on the image. The entire camera and screen assemblies are mounted to a central rod that passes through the vacuum flange on the rear of the ion source, allowing the screen and camera to move longitudinally while keeping the distance between the two fixed; a vacuum window is mounted in the centre of this flange. Three support rods attached to the outer face of the flange provide extra stability for the camera support, which is fixed to them by a three-arm spider. Two rulers mounted to the screen support structure allow calibration measurements on the relative size and rotation of the pepperpot images. A light-tight bellows encloses the light path between the vacuum window and the camera lens to ensure the optical path is light tight. With the described set up it is possible to measure the 4D transversal emittance at various points along the beam axis and therefore it allows evaluation of the emittance growth and an estimate of the amount of smear on the image. The vacuum flange, with complete pepperpot assembly, was then installed on the ISDR. Data taking is currently at the preliminary stage: an example data image is shown in Figure 8.

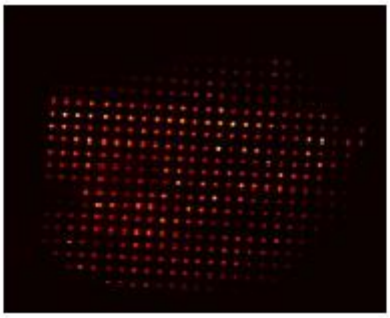

FIGURE 8: A false-colour intensity image taken with the pepperpot emittance scanner of the ion source beam, at a beam energy of 16.5 keV. The imaged area is 90 x 73 mm^2.

Further analysis of the image data is required to extract emittance information. Thus far three scintillator materials have been tested: P46 phosphor sputtered onto a glass plate, plastic and ruby. Of these, only ruby has been robust enough to withstand the beam at 50Hz, the other two have been destroyed.

There have also been problems with the translational vacuum feed-through, this is being replaced with a set of bellows. The support structure is also being modified further to make it stiffer and less prone to vibration.

SUMMARY

A retarding potential energy analyzer has been developed and installed on the ISDR at ISIS. The beam energy spectrum width has been found to be 17.6 eV +/- 1.5 eV. This spectrum width has been shown to increase with discharge current.

A pepperpot emittance measurement device is currently under development, this will provide a full understanding of beam emittance and allow the LEBT on the Front End Test Stand being built at RAL to be designed.

REFERENCES

1. A.P. Letchford et al, "The RAL Front End Test Stand", EPAC'06, Edinburgh, June 2006.
2. D.C. Faircloth and J.W.G. Thomason, "Extending the Duty Cycle of the ISIS H- ion source, Thermal Considerations", EPAC'04, Lucerne, June 2004.
3. D.C. Faircloth et al, "Practical experience in Extending the Ion Source and Injection System H^- Ion Source Duty Cycle", Rev. Sci. Instrum. 77, 03A520 (2006), March 2006.
4. J. Pozimski et al, "LEBT Simulations and Ion Source Beam Measurements for the Front End Test Stand (FETS)", EPAC'06, Edinburgh, June 2006.