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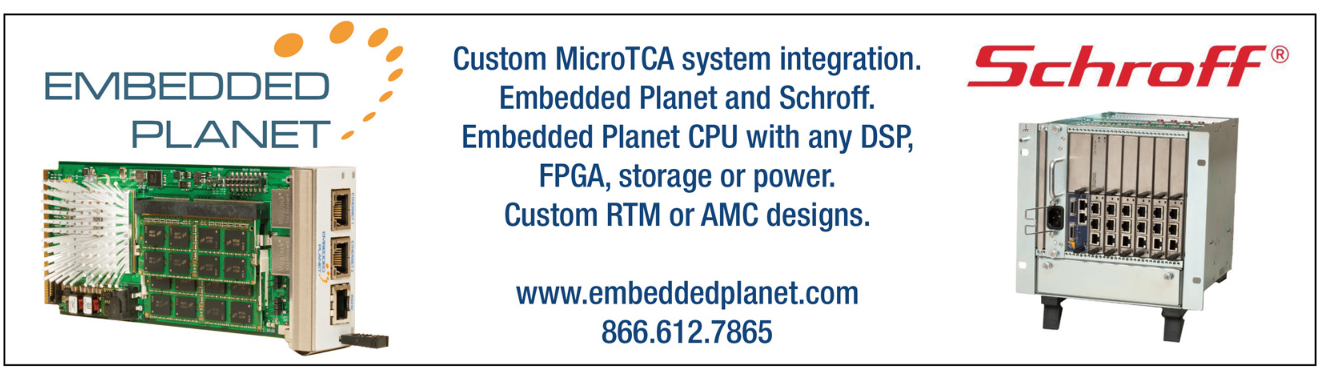

REVIEW OF SCIENTIFIC INSTRUMENTS **83**, 02A701 (2012)

Optimizing the front end test stand high performance H^- ion source at RAL[a)]

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The aim of the front end test stand project is to demonstrate that chopped low energy H^- beams of high quality can be produced. The beam line currently consists of the ion source, a 3 solenoid low energy beam transport and a suite of diagnostics. A brief status report of the radio frequency quadrupole is given. This paper details the work to optimize the ion source performance. A new high power pulsed discharge power supply with greater reliability has been developed to allow long term, stable operation at 50 Hz with a 60 A, 2.2 ms discharge pulse and up to 100 A at 1.2 ms. The existing extraction power supply has been modified to operate up to 22 kV. Results from optical spectroscopy measurements and their application to source optimization are summarized. Source emittances and beam currents of 60 mA are reported. © *2012 American Institute of Physics*. [doi:10.1063/1.3655526]

I. INTRODUCTION

A. FETS

Front end test stand (FETS) is being developed as a generic injector for future high power proton particle accelerators. The aim of the FETS is to demonstrate the production of a 60 mA, 2 ms, 50 Hz chopped H^- beam at 3 MeV with sufficient beam quality for future applications. FETS consists of a high power ion source, a 3 solenoid magnetic low energy beam transport (LEBT), a 324 MHz, 3 MeV, 4-vane radio frequency quadrupole (RFQ), a fast electrostatic chopper, and a comprehensive suite of diagnostics.

B. The FETS ion source

The H^- Penning surface plasma source was first developed by Dudnikov[1] in 1974. The FETS source[2] is a development of the operational Penning source at Rutherford Appleton Laboratory (RAL) which has successfully provided beam for the ISIS spallation neutron source for over 25 years.

Caesium and hydrogen are fed into the pulsed discharge through the hollow anode shown in Fig. 1. The beam is extracted through a 0.6 mm by 10 mm slit in the aperture plate (plasma electrode). After extraction the beam is bent through a 90° sector magnet (Fig. 2) mounted in a refrigerated caesium trap and further accelerated by a post extraction acceleration gap to 65 keV.

C. The FETS beam line

At present the FETS beam line consists of a 3 solenoid LEBT and a suite of diagnostics shown in Fig. 2. The RFQ will be installed at the position of the diagnostics vessel.

II. HARDWARE DEVELOPMENTS

A. FETS status

The RFQ design is complete and an initial machining test is being performed. The RFQ will be constructed in four

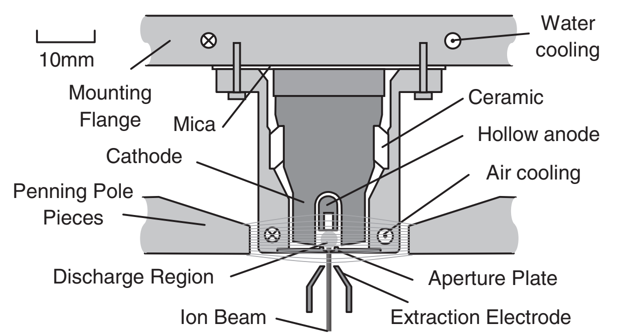

FIG. 1. A schematic of the FETS ion source.

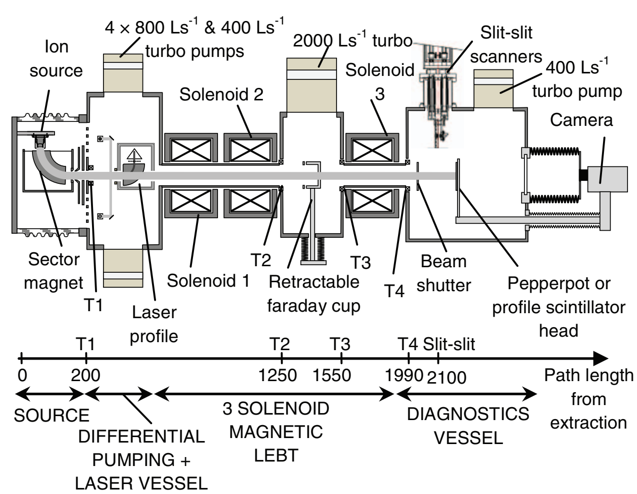

FIG. 2. (Color online) A schematic of the FETS LEBT beam line.

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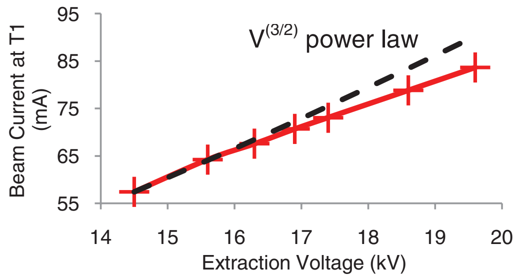

FIG. 3. (Color online) Beam current vs extraction voltage.

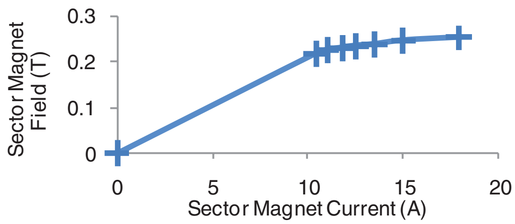

FIG. 4. (Color online) Sector magnet field vs current.

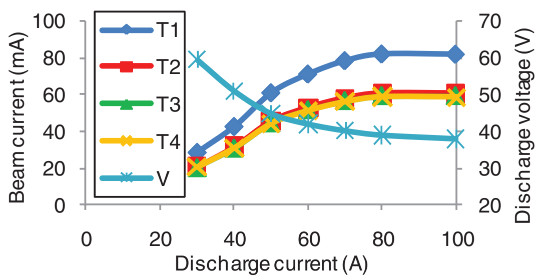

FIG. 5. (Color online) H^- beam currents and discharge voltage vs discharge current.

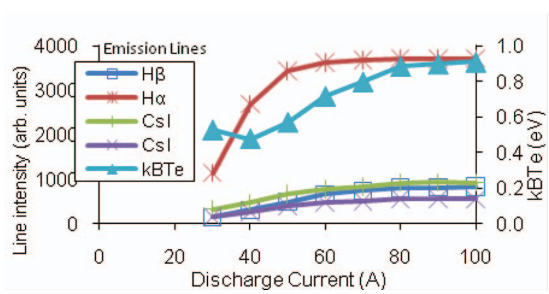

FIG. 6. (Color online) Optical emission peaks vs pulsed discharge current.

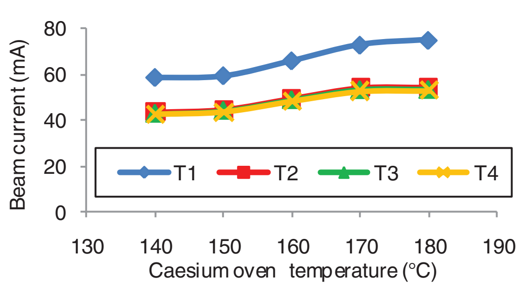

FIG. 7. (Color online) H^- beam currents vs caesium oven temperature for a 55 A discharge.

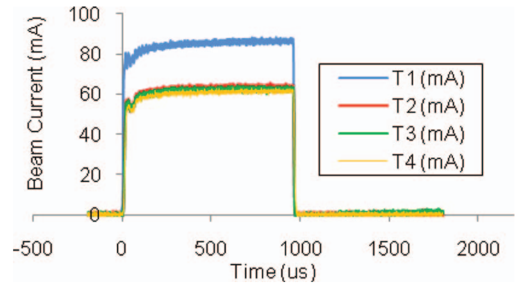

FIG. 8. (Color online) Beam current profiles of 62 mA at 50 Hz 1 ms. (1.2 ms, 60 A discharge, 19.6 kV extraction voltage, 65 keV beam, 180 °C caesium oven, 16 mLmin^{-1} H_2.)

1 m long sections. Each section is assembled from 4 blocks to make up the 4 vanes. The entire RFQ will be bolted together using a 3D o-ring and RF seals. Test assembles have confirmed this approach is feasible.

B. Power supplies

The existing extraction power supply has been modified to allow operation at 22 kV. A new high power pulsed discharge power supply with greater reliability has been developed to allow long term, stable operation at up to 50 Hz with a 60 A, 2.2 ms discharge pulse. At lower duty cycles currents up to 100 A can be produced.

C. Caesium delivery system

To improve the reliability of the caesium delivery system, thermal cut-out switches have been implemented on the caesium oven and transport line heaters. In the event of a control or monitoring failure the switches limit the temperature and prevent over caesiation incidents. This technology has also been implemented on ISIS.

D. Electrode configuration

The greatest beam currents are obtained for 1.1 mm extraction electrode jaw spacing. Wider jaw spacing's reduce beam and extraction current. The post extraction acceleration gap is set to 6 mm, this gives the best beam transport for an acceptable rate of high voltage breakdowns.

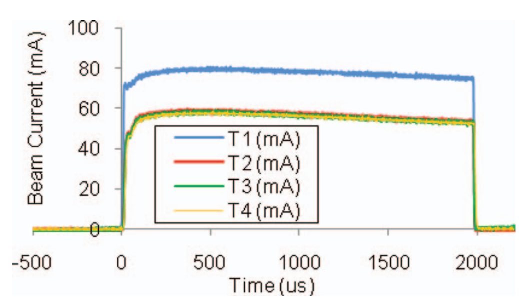

FIG. 9. (Color online) Beam current profiles of 60 mA at 25 Hz. (2.2 ms, 64 A discharge, 19.6 kV extraction voltage, 65 keV beam, 190 °C caesium oven, 16 mLmin^{-1} H_2.)

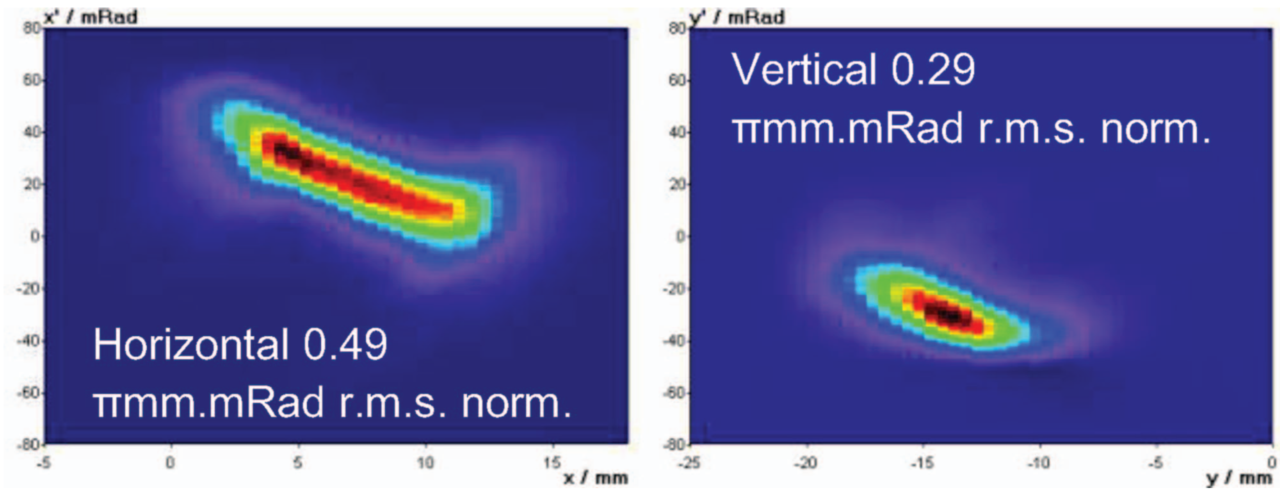

FIG. 10. (Color online) Beam emittance at the entrance of the RFQ for the beam shown in Fig. 8.

III. EXPERIMENTS

A. Vary extraction voltage

Figure 3 shows how the H^- beam current increases with extraction voltage. Above 16 kV the beam current departs from the $V^{3/2}$ power law, but continues to increase.

The maximum extraction voltage achievable is limited by the maximum field that can be produced in the sector magnet. Figure 4 shows how the sector magnet field varies with applied current. The saturation of the magnetic circuit combined with the power supply capability limits the peak sector magnet field to 0.253 T. This restricts the maximum extraction voltage to 19.6 kV.

B. Vary pulsed discharge current

Figure 5 shows how the beam current increases with the discharge current and how the discharge voltage drops. Above 80 A discharge current, the H^- beam current does not increase any further.

An optical spectroscope[3] monitors the light from the discharge as the discharge current increases. It is possible to work out the electron temperature $k_B T_e$ from the ratios of the peaks.[3] The electron temperature does not increase for discharge currents greater than 80 A as shown in Fig. 6.

C. Vary caesium oven temperature

Figure 7 shows how the beam current varies with Cs oven temperature. The H^- beam current increases rapidly between 150 and 170 °C, above this range the beam current increases more slowly.

D. LEBT transmission

The 3 solenoid LEBT settings have been optimized to give maximum transmission.[4] For high currents the beam at the ground plane of the post acceleration gap is quite large and does not fit in the acceptance of the LEBT. Most of the beam is lost in the first two solenoids, however, for beam currents at T1 of above 80 mA it is possible to transport 60 mA to the entrance of the RFQ. The position of the beam focus can be moved by changing the current in the third solenoid.

E. Optimum performance

Previous experiments[5] have shown that running at discharge pulse lengths above 1.2 ms at 50 Hz give unacceptable droop in the H^- beam current. Experiments varying hydrogen gas pulse timing and using double hydrogen pulses have failed to mitigate this droop. It is not currently possible to deliver all FETS beam current requirements simultaneously.

However, by using the optimum source parameters it is possible to produce a 62 mA, 50 Hz, 1 ms beam pulse at the entrance of the RFQ as shown in Fig. 8. By reducing the repetition rate to 25 Hz it is possible to produce a 2 ms 60 mA beam pulse as shown in Fig. 9. The beam emittances for a 62 mA beam at the entrance of the RFQ are shown in Fig. 10.

IV. DISCUSSION AND CONCLUSIONS

The discharge voltage levelling out (Fig. 5) indicates that increasing the discharge current above 70 A starts to push the discharge towards the thermal arc region. At the same current the electron temperature goes above the H^- electron affinity energy of 0.75 eV (Fig. 6). Detachment processes limit the H^- current from increasing any further.

All the FETS beam requirements have been achieved but not simultaneously. All parameters have been optimised for the current source design. The only option to achieve a 2 ms 50 Hz beam is a scaled source. Funding for development work will be available in FY 2012.

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