ASSESSING THE TRANSMISSION OF THE H^- ION BEAM ON THE FRONT END TEST STAND

S. Lawrie, D. Faircloth, A. Letchford, M. Perkins, ISIS Neutron Source, RAL, Oxfordshire, UK
C. Gabor, ASTeC, RAL, Oxfordshire, UK
J. Pozimski, Department of Physics, Imperial College, London, UK

Abstract

The front end test stand (FETS) [1] is entering the next stage of construction and commissioning, with the three-solenoid magnetic low energy beam transport (LEBT) line being installed. A thorough characterization of the beam leaving the Penning H^- ion source has been performed. This includes measurements of the beam current using toroids and of the transverse emittance using slit-slit scanners. These measurements are performed over a wide range of source discharge and extraction parameters in order to understand how the transmission may be improved. Comments on the quality of the beam to be injected into the FETS radio frequency quadrupole (RFQ) are given.

INTRODUCTION

The FETS is being constructed at the Rutherford Appleton laboratory (RAL) in the UK to demonstrate perfect chopping [2] of a high intensity H^- ion beam. The overall aim is to fully transport 3 MeV H^- ions with a pre-chopped beam current of 60 mA in pulses up to 2 ms long at 50 Hz. Additionally, the beam must maintain a high quality to the end of the beamline with transverse normalised RMS emittances of 0.25 π mm mrad. This front end will be suitable as an injector for high power proton accelerator (HPPA) machines; including upgrades to the highly successful ISIS pulsed spallation neutron source, accelerator-driven subcritical reactors (ADSR) and a neutrino factory. This paper will outline the present status of the H^- ion beam and its successful transmission through the LEBT.

PRESENT STATUS

The low-energy section of FETS is now fully completed and is undergoing a thorough commissioning process.

The aim is to understand the characteristics of the H^- beam and ensure it is suitable for insertion into the RFQ; the next item in the beamline to be constructed [3,4]. FETS currently consists of a Penning-type H^- ion source (an upgraded version of that used on ISIS) [5]; a 2D tomographic laser photodetachment profile monitor [6]; a three-solenoid LEBT [7,8]; and a movable diagnostics vessel used to characterise the beam after each item of the beamline is installed. The impressive suite of diagnostics currently installed on FETS is illustrated in Fig. 1.

MEASUREMENT PROCEDURE

The transmission of the H^- beam through the LEBT was assessed as follows. Before the installation of the solenoids, the diagnostics vessel was used to measure the current, profile and transverse emittance of the beam immediately after the laser diagnostics vessel. Preliminary results using this setup are given in [9]. Subsequent to the solenoids' installation, the diagnostics vessel has now been used to study the beam under the same ion source conditions for various LEBT settings. This allows the comparison of the current and emittance before and after the LEBT. Current measurement diagnostics have been installed in the pumping vessel between solenoids 2 and 3, which allow for the assessment of stripping losses of the H^- beam due to the residual gas pressure within the LEBT beam pipe.

Sparking problems inside the platform high voltage power supply meant that measurements before the LEBT installation were limited to a 45 keV beam. This problem has now been fixed and FETS routinely runs at its design RFQ injection energy of 65 keV. Nevertheless, some measurements were still made at lower energies to allow for a fair analysis of the LEBT transmission.

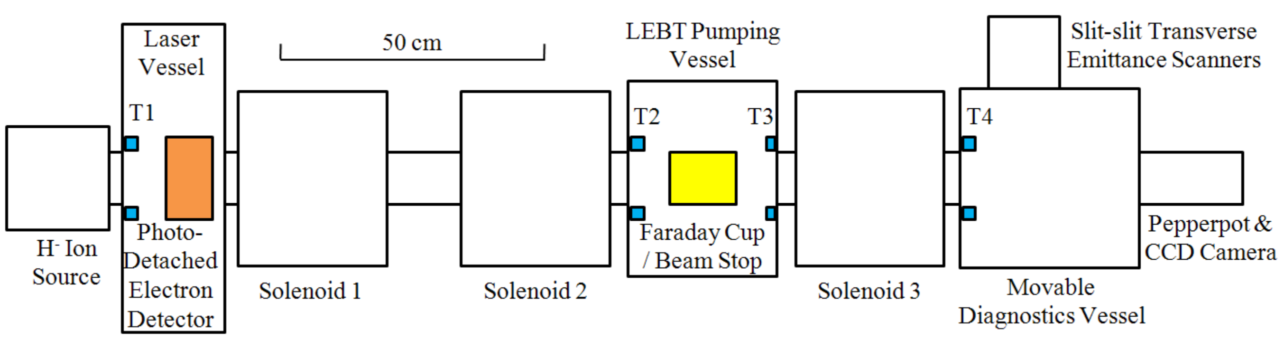

Figure 1: Present FETS diagnostics equipment, shown to scale. Labels T1-4 denote beam current transformer toroids.

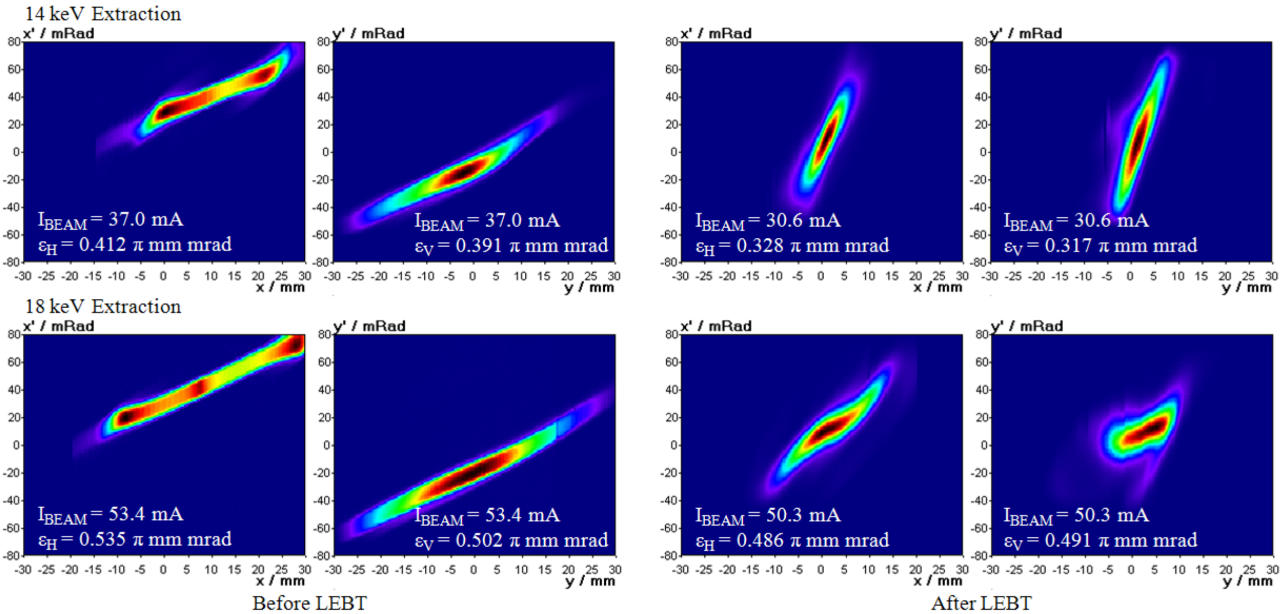

Figure 2: Horizontal and vertical emittance plots before (left pairs) and after (right pairs) the LEBT solenoids for extraction energies of 14 keV (top row) and 18 keV (bottom row). The post-acceleration potential applied was 24 kV.

TRANSVERSE EMITTANCE

Varying the source parameters can have very subtle effects on the beam phase space, which is already very small due to focussing in the LEBT. Therefore, the slit-slit emittance scanners [10] require an improved resolution to measure these small features. By oversampling in angle and deconvoluting the phase space plots using the Lucy-Richardson algorithm [11], emittance scans are now routinely taken at four times the normal resolution. Improving the scan speed to compensate for the higher number of pixels now allows for wide-range emittance scans accurate to 0.25mm x 1mrad in less than 20 minutes. Results shown in this paper were all taken using this technique.

Recent modifications to the ion source [9, 12, 13, 14] have vastly reduced the divergence of the beam, leading to reduced emittance growth and collimation. Nevertheless, the beam is still quite large and divergent before the LEBT, as can be seen in the left-hand images of Fig. 2. With the solenoids on at design currents, the beam can be seen in the right-hand images to be well focused after the LEBT. The flat-top beam current and emittance is also given in Fig. 2. The small amount of beam loss and resulting reduction in emittance is attributed to halo scraping.

The Child-Langmuir law states that if the plasma generator is able to supply sufficient current density, then the beam current scales with the extraction voltage. This greater space charge, combined with the movement away from matched extraction, leads to a larger beam in the bottom row of Fig. 2 (18 keV extraction) compared to the top row (14 keV). However, despite a constant post-acceleration voltage – and hence focussing – of 24 kV applied, there are large differences in the beam's orientation and filamentation after the LEBT for different extraction energies. The beamline optics are the same for each case; so the changes seen in the phase space may indicate that the LEBT is not fully space charge compensated, resulting in the non-linear perturbations seen [8]. Therefore, for optimum beam transmission, the solenoids must be tuned for each extraction voltage.

TRANSPORTED CURRENT

Another indicator of how the extraction and post-acceleration voltages affect the beam transport through the LEBT is shown in Fig. 3. For a set of extraction energies, the post-acceleration voltage is varied. The post-extraction acceleration electrode acts as a lens, adding a focus to the beam to reduce collimation through the laser vessel; before injection into the first solenoid. Hence whilst the current through the first toroid (immediately after the ion source) hardly changes upon increasing the post-acceleration, more beam makes it through the laser vessel and into the LEBT. However it can be seen that at lower extraction energies, high post-acceleration voltages actually over-focus the beam, resulting in beam loss.

This behaviour shows that the LEBT is well designed to operate at high ion source extraction voltages and high total beam energies, with an initially divergent beam. In this mode of operation, there is unfortunately a 20% reduction in beam current due to collimation in the laser vessel. However the remaining 55 mA of beam is almost perfectly transported through the LEBT, with 4% losses attributed to residual gas stripping of the H^-. It must be noted that this result is with neither with the ion source optimised to give the best output, nor with the solenoids adjusted away from their design currents based on an idealised ion source output beam and unknown amounts of space-charge compensation. Tuning the system will inevitably lead to an even higher transmission.

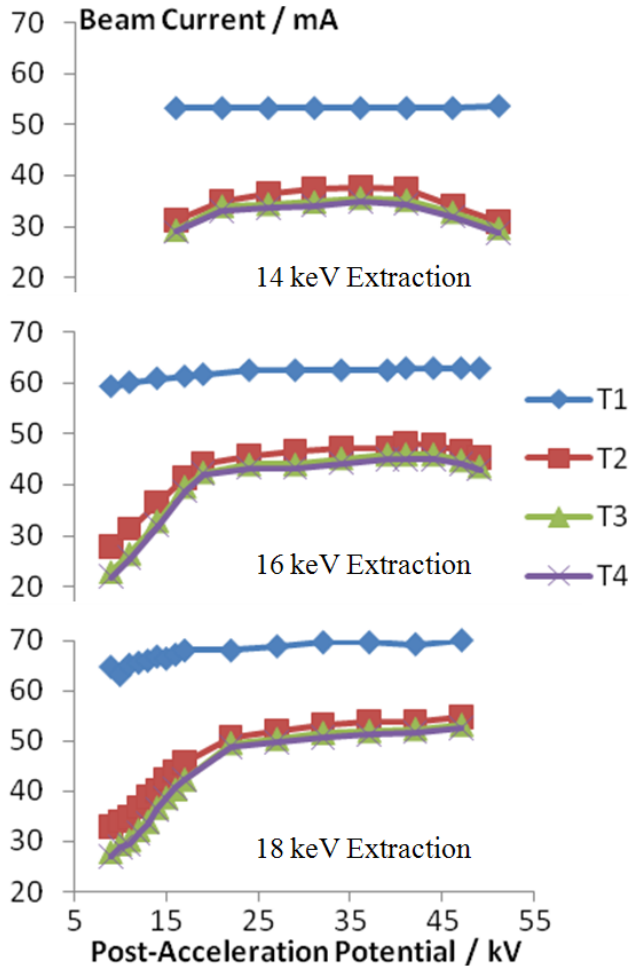

Figure 3: Effect of post-acceleration on beam transport.

PRESENT BEAM STATUS

Plots of the current and emittance now routinely produced on the FETS LEBT are shown in Figs. 4 and 5. The high frequency noise on the toroid current measurements in Fig. 4 is caused by the solenoid power supplies switching at 25 kHz. The source of this problem has been found and a solution is being formulated. The emittance and Twiss parameters measured throughout the duration of the beam pulse are shown in Fig. 6.

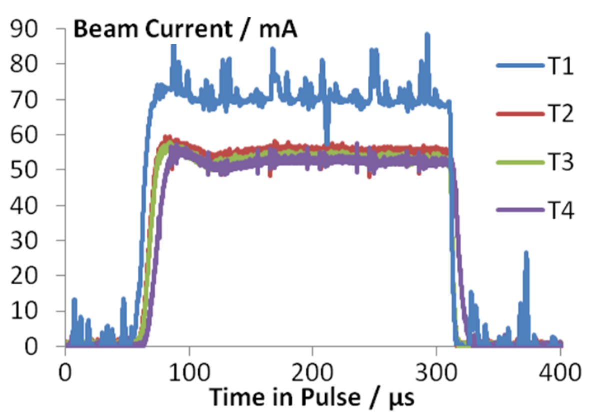

Figure 4: Beam currents measured in the four LEBT toroids at design beam energy and solenoid settings.

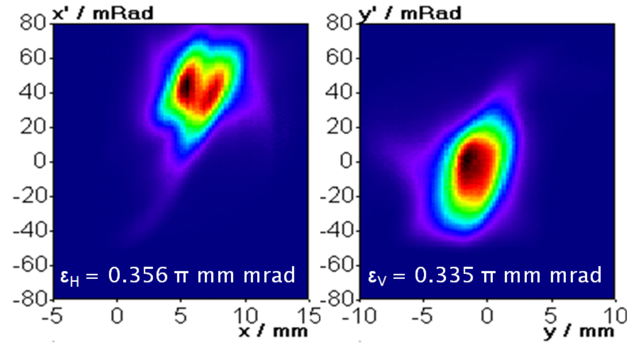

Figure 5: Phase space plots of the beam at design settings.

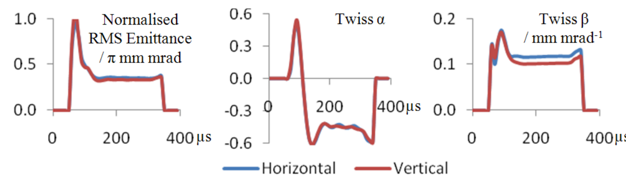

Figure 6: Variation of the emittance and twiss parameters with time in the pulse for the beam plotted in Figs. 4 & 5.

DISCUSSION

Ion source misalignment causes the beam to be off-centre horizontally, leading to the filamentation in Fig. 5. A new ion source alignment system is being designed, and the Lambertson dipole steerers in the solenoids will soon be in routine use to ensure a perfectly centred beam.

The beam should converge to a waist just inside the RFQ. The emittance scanners are about 5 cm downstream of the waist so the beam is slightly divergent in Fig. 5. Adjusting solenoid 3 varies the position of the waist.

Fig. 6 shows that the beam takes about 70 µs to settle in orientation. This is due to both the overshoot in the extraction power supply and the time it takes to build up space charge compensation. Therefore, it is likely that the start of the beam will be lost in the RFQ. However, the remaining beam pulse has a steady state current of 53 mA and emittance of 0.35 π mm mrad, which is close to meeting the FETS specifications. Further improvement should be possible by fine tuning the LEBT for higher extraction voltages.

REFERENCES

[1] A. Letchford *et al*, IPAC'10, MOPEC075.
[2] M. Clarke-Gayther, EPAC'08, THPP094.
[3] J. Pozimski *et al*, LINAC'08, MOP088.
[4] P. Savage *et al*, IPAC'10, MOPD056.
[5] D. Faircloth *et al*, Rev. Sci. Instr. 81 (2010) 02A721.
[6] C. Gabor *et al*, IPAC'10, MOPE067.
[7] S. Jolly *et al*, EPAC'06, TUPLS090.
[8] J. Back *et al*, IPAC'10, MOPEC078.
[9] S. Lawrie *et al*, Rev. Sci. Instr. 81 (2010) 02A707.
[10] S. Lawrie *et al*, EPAC'08, TUPC057.
[11] W. Richardson, J. Opt. Soc. Am. 62 (1972) p55-59.
[12] J. Thomason *et al*, EPAC'04, TUPLT141.
[13] D. Faircloth *et al*, EPAC'08, MOPC142.
[14] S. Lawrie *et al*, EPAC'08, MOPC150.