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STATUS OF THE H⁻ PRE-INJECTOR TEST STAND AT ISIS

S. Lawrie*, R. Abel, D. Faircloth, T. Sarmento, J. Speed, O. Tarvainen
UKRI Science and Technology Facilities Council, Rutherford Appleton Laboratory,
Harwell Campus, Oxfordshire, OX11 0QX, UK

Abstract

The H^- linac pre-injector used at the ISIS spallation neutron and muon source is being upgraded to include a medium energy beam transport (MEBT) line after the radio frequency quadrupole (RFQ). The improved beam transport allows the use of a more modern and reliable RF-driven H^- ion source. To test the new ion source and MEBT for long-term end-to-end reliability, an entire pre-injector test stand (PITS) is being assembled offline. All beamline components are installed on the PITS and electrical services are nearing completion. The latest performance of the ion source is discussed, including methods to improve RF noise immunity.

PRE-INJECTOR UPGRADE

The ISIS synchrotron (ring) uses multi-turn charge-exchange injection of H^- ions to achieve beam intensity of 5×10^{13} protons per pulse at 50 Hz repetition rate. To generate the required beam to target, a 70 MeV drift-tube linear accelerator (DTL) injector consisting of four 'tanks' delivers 250 μs-long pulses to a carbon stripping foil, which are subsequently injected over ≈120 turns around the ring. The DTL is fed by a pre-injector consisting of an H^- ion source, three-solenoid magnetic low energy beam transport (LEBT) and 202.5 MHz, 665 keV radio-frequency quadrupole (RFQ). Space constraints during the design and installation of the pre-injector required the RFQ to be located immediately before the DTL. With no matching optics between the RFQ and DTL, 30% of the beam is lost in the first tank. Similarly, the somewhat large emittance beam from the Penning-type H^- ion source analysing dipole cannot be transported fully through the LEBT. In total, of the ≈50 mA output from the ion source, only 25 mA of beam arrives at the ring. With 15 years of fault-free RFQ operation, space has been cleared to shift it upstream 2 m and insert a medium energy beam transport (MEBT) line to facilitate matching to the DTL. With beam-loss minimised, the ion source no longer needs to supply as many H^- ions. Therefore a more modern – albeit lower output current – RF-driven H^- ion source may be used. The pre-injector upgrade has been described previously in detail [1, 2]. This paper outlines the latest status, including ion source beam results and noise mitigation strategies.

RF-DRIVEN H⁻ ION SOURCE

The Penning-type caesiated H^- ion source used at present on ISIS delivers beam current in excess of 50 mA at high duty factors. Its main drawback is the susceptibility of extremely compact plasma-facing components to sputtering by caesium. This limits its lifetime to around three weeks. With the more modest 30 mA current requirement afforded by the MEBT, alternative ion source technology may be used. A non-caesiated RF-driven volume-type H^- ion source is in development which promises much longer lifetimes of at least six months. This relaxes maintenance schedules and improves overall facility reliability. The RF ion source plasma operates well at 5% duty factor, delivering 1 ms, 70 kW, 3 MHz RF pulses extremely reliably at 50 Hz [3]. With voltages applied to the extraction electrodes, 15 mA was generated on the first pulse [4]. This is an encouraging result, giving confidence that over 30 mA will be possible without the use of caesium, once plasma parameters have been optimised and voltages stabilised.

Measurements were performed [5] to determine the efficiency of coupling RF power into the plasma, as shown in Fig. 1. Losses occur primarily in parasitic coupling to nearby metalwork, plus due to the radial gap between the RF-coil and plasma chamber – necessary for the inclusion of water cooling channels. At typical operating powers between 30-70 kW, the coupling efficiency is approximately constant at 50%, whereas the light emission (and hence plasma density and H^- ion production) increases without saturation. This suggests that the extracted beam current can be set by adjusting the RF power, without affecting the efficiency.

RF Noise Mitigation

Significant and intolerable RF pickup was found on diagnostic equipment and even the main building earth. There are multiple possible causes for this. The RF-coil which generates the plasma is connected to a matching circuit via ≈200 mm legs. The RF voltage on the coil is around 10 kV, which creates an electric field between the exposed input leg and the nearest laboratory ground plane. Therefore, it may

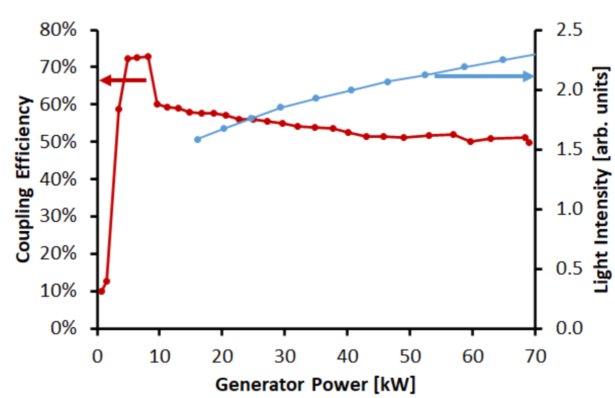

Figure 1: Proportion of RF power delivered by the coil actually coupling into the plasma (red). Normalised total optical emissions from the plasma (blue).

* scott.lawrie@stfc.ac.uk

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be expected that a non-negligible oscillation of the nominally zero-potential ground may occur, which then propagates across the building. To prevent this, an RF shield has been installed around the ion source and matching circuit to prevent field leakage.

A beam current transformer toroid is located close to the ion source outlet aperture to measure the extracted H^- beam current. The toroid is sensitive to stray magnetic fields, so it is conceivable that the fringe field from the solenoidal RF-coil couples to it, resulting in a measurable signal, even without beam. A ferromagnetic plate has been installed in front of the toroid to shield it from the RF-coil.

The matching circuit couples the 50 Ω amplifier to the variable ≈2 Ω plasma load. The match is not perfect, however, so reflections travel back up to the amplifier. This means the outer screen on the coaxial transmission line contains an RF signal, which will then radiate outward onto nearby cabling, generating RF pickup. The amplifier and transmission line have been moved away from all other racks, cables and equipment. In addition, the coax has been housed inside its own dedicated magnetically-screened trunking, forming a triaxial line, to prevent any reflected signals radiating outward.

Finally, mains filters have been installed on the electrical inputs of the ion source high voltage deck and the RF amplifier, such that any local noise cannot propagate onto the other mains-powered equipment racks.

BEAM DIAGNOSTICS

As well as the ion source toroid, other toroids are located in the LEBT diagnostics vessel; at the entrance and exit of the RFQ, and at the end of the MEBT. As shown in Fig. 2, the LEBT vessel also contains two Allison-type emittance scanners and a retractable Faraday cup. The Faraday cup was added to mitigate the risk of noise immunity measures being unsuccessful: the Faraday cup is much less susceptible to RF fields than the toroid, so is a useful secondary diagnostic to validate beam current results. Being water cooled, it also serves as a beam dump; stopping beam entering the RFQ in the event of a machine trip.

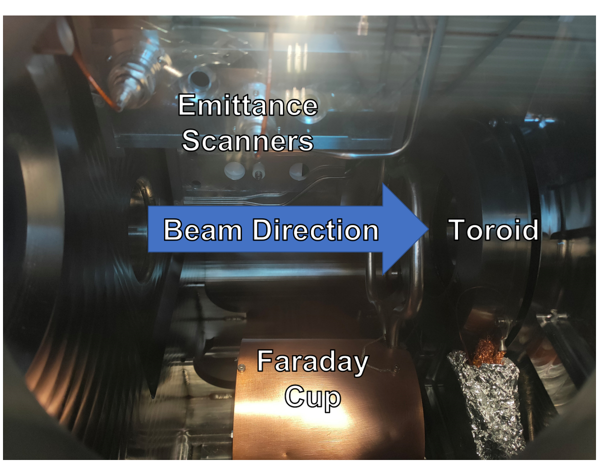

Figure 2: LEBT beam diagnostics vessel interior.

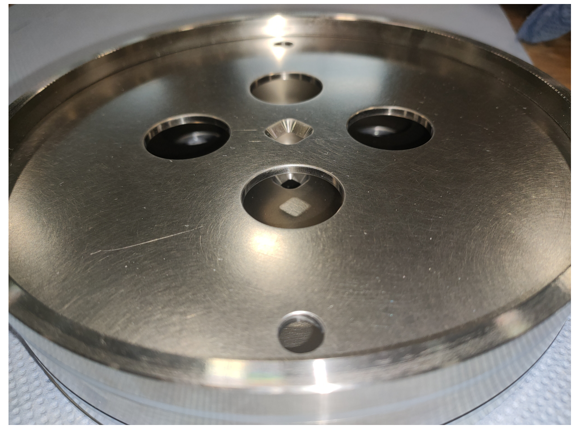

Figure 3: RFQ acceptance mask during alignment.

The emittance scanners will be used to validate 36 keV ion source extraction simulations [6]. When later moved to a post-MEBT position, their cooling and electrostatic deflection systems are also capable of measuring the 665 keV beam to ensure correct matching to the DTL. The emittance scanners will not be moved to the RFQ location to assist with setting up the LEBT for RFQ injection. Instead, a set of four collimating apertures will be installed temporarily to mask the LEBT beam into the RFQ acceptance [7], as shown in Fig. 3. An automated tuning procedure will adjust the LEBT solenoids until maximum transmission is measured on a Faraday cup after the mask. These solenoid settings will then be used as a starting point for tuning into the RFQ – bearing in mind that the transmission will likely be overestimated by a few percent, since the mask cannot replicate the longitudinal RFQ acceptance.

Four extremely compact beam position monitors (BPMs) are installed between the MEBT quadrupole magnets. Measuring just 30 mm long, they are just visible between the magnet coils in Fig. 4. Having been calibrated and aligned offline, Fig. 5 shows that the BPMs have excellent linearity

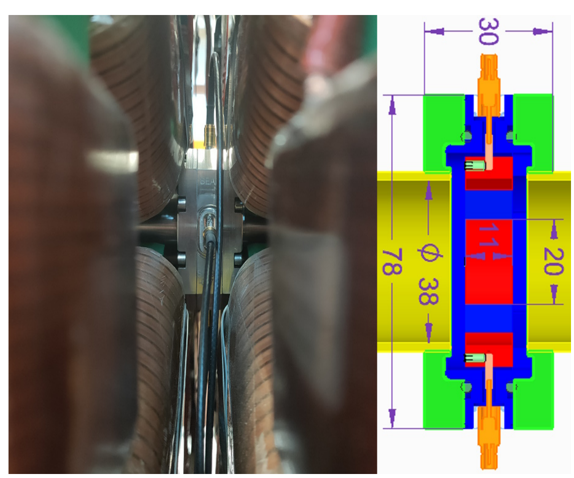

Figure 4: One of four beam position monitors between the coils of the MEBT quadrupole magnets (left). Principle internal dimensions (right).

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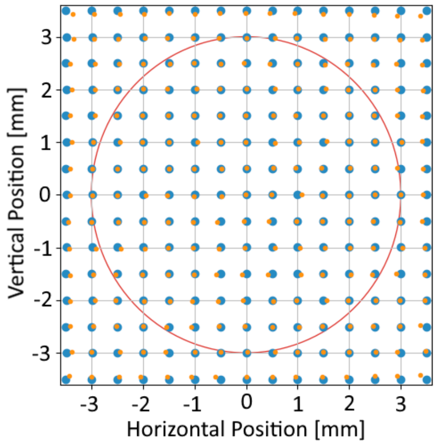

Figure 5: Measurement linearity of the BPM. Blue points show measurement position, orange points show calculated position from detector and electronics. Note the reduction in measurement accuracy outside the red good field region.

response ±3 mm away from the beam axis, with a position measurement accuracy of 0.12 mm. As well as facilitating the correction of transverse beam misalignment, the BPMs will be used to determine the bunch time of flight and hence energy. This will allow the correct phasing of the quarter-wave resonator (QWR) re-bunching cavities.

MEBT

Four two-gap 202.5 MHz QWRs operating at -90° phase maintain the longitudinal microbunch structure of the RFQ beam. Each QWR consists of a copper drift tube suspended inside a copper-plated stainless steel cylindrical cavity. Difficulties achieving acceptable plating quality have delayed delivery, but the solution shown in Fig. 6 has given confidence to proceed to batch production. Final delivery and installation is expected toward the end of 2023.

An electrostatic sweep chopper prepares the H^- beam for injection into the synchrotron. The first ≈100 μs of the LEBT beam pulse is mismatched to the RFQ until space charge compensation is established fully. The chopper will remove the mismatched initial portion, leaving a clean, square pulse with no emittance growth. The chopper plate voltages then burst at the 1.3 MHz ring RF frequency, removing up to 40% of the RFQ microbunches. This leaves a train of minipulses for clean, loss-less injection into the ring RF buckets. Injecting an un-chopped beam at present on ISIS is one of the main sources of synchrotron loss and machine activation, so the new chopper will bring large operational benefits. It will also give more flexibility during machine physics experiments, enabling a wide range of beam timing schemes to be prepared for synchrotron studies.

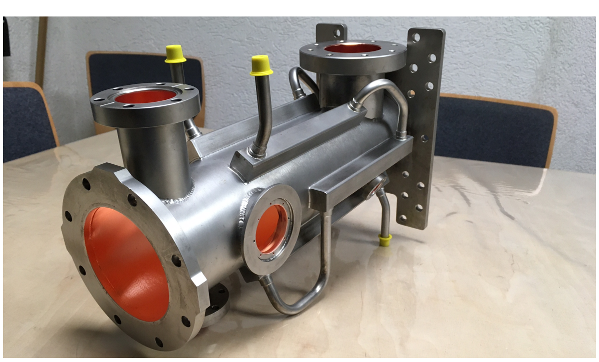

Figure 6: Quarter-wave resonator cavity prototype.

Three vacuum isolation valves and eight quadrupole magnets with integrated steering dipole coils complete the MEBT layout. With over 20 beamline components in less than 2 m of space, the MEBT is a challenging build; it is split into three sub-rafts to ease installation and maintenance.

CONCLUSION AND OUTLOOK

The first H^- ion beam has been extracted successfully from the ion source. Significant mechanical modifications have been made to improve RF noise immunity of diagnostic equipment. Final electrical wiring and component installation is underway, with an aim to produce a LEBT beam by Summer 2023. A detailed measurement campaign including emittance scans will be completed before focussing the beam through the RFQ acceptance mask. Pending delivery of the QWRs, the RFQ and MEBT will be ready to accelerate beam by Winter 2023. Thereafter, the entire pre-injector will be soak-tested for one year in order to prove its viability and reliability for installation on ISIS. The pre-injector is a major upgrade for ISIS and will improve facility availability considerably.

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