INSTALLING THE VESPA H⁻ ION SOURCE TEST STAND AT RAL

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Abstract

A Penning-type negative hydrogen (H^-) ion source has been used reliably on the ISIS pulsed spallation neutron and muon facility at the Rutherford Appleton Laboratory (RAL) in the UK for almost 30 years. However a detailed study of the ion source plasma and extraction has never been undertaken. If these properties were known, the beam emittance and losses due to collimation could be reduced, and the lifetime increased. This paper summarises the progress made on installing a Vessel for Extraction and Source Plasma Analyses (VESPA) to fill the knowledge gap.

MOTIVATION

The ISIS pulsed spallation neutron and muon facility at the Rutherford Appleton Laboratory (RAL) in the UK uses a Penning-type surface plasma H^- ion source. Over the last decade, significant R&D effort has been undertaken to upgrade the ion source in order to improve transmission on ISIS itself and for use on the Front End Test Stand (FETS) [1]. Resulting modifications include stronger focussing post-acceleration electrodes, giving >95% LEBT transmission; a re-designed combined function sector dipole magnet to reduce emittance growth by 30%; and improved cooling of the source cathode, leading to a ten-fold increase in beam duty-cycle [2].

To achieve further improvements in beam current, emittance, transport and lifetime, complete understanding of the ion source plasma itself is required, and the extraction system needs re-designing from the ground up. As such, a Vessel for Extraction and Source Plasma Analyses (VESPA) has been constructed to perform the required studies and implement design changes.

VESPA DESIGN PHILOSOPHY

The existing ISIS and FETS ion sources are oriented for vertical extraction before the beam is deflected 90° by a sector dipole magnet, then post-accelerated to the RFQ input energy. Beam tracking simulations indicate that up to 50% of extracted beam particles are collimated on the sector dipole magnet. This is because the diode extraction inherently creates a divergent beam; compounded by significant space-charge forces of the ~18 keV drifting beam. With the first beam diagnostic after the dipole and post-acceleration measuring around 60 mA of beam current, it is unknown how much current is actually extracted from the source: it is likely almost double. The VESPA will remove the dipole, reduce drift lengths, have better focussing in the extraction optics and bring the beam diagnostics closer to extraction. In this way, losses can be minimised and the emittance optimised.

VESPA Mk. 1

Because of the radical change in mounting orientation and vacuum pumping speed with the removal of the dipole, the proof-of-principle was tested using an existing vacuum vessel [3]. Beam was extracted and measured on a Faraday cup but due to the non-standard high-voltage arrangement, it is unclear how much the signal was affected by residual gas electrons [4]. Nevertheless, the ion source performed well, so the design of a bespoke vessel could commence.

VESPA Mk. 2

The VESPA is designed to perform a wide variety of rigorous diagnostics on both the ion source plasma and extracted beam. Therefore a large number of ports are required to view the source from all angles. A high resolution monochromator will be used to improve upon initial emission spectroscopy studies [5]. Drifts to beam diagnostics are small to limit space-charge emittance growth, but long enough to install new extraction electrodes. Beam diagnostics include: current transformer toroid; Faraday cup; energy analyser; slit-slit emittance scanners and a pepperpot emittance/profile monitor which can measure the beam at different longitudinal positions.

The ultimate aims for VESPA are to provide a long lifetime ion source for ISIS operations and a high duty-cycle source for FETS. Therefore the same vessel flange dimensions are used such that the final design can be transferred to ISIS or FETS. One vacuum pump with a gate valve is installed, rather than two on ISIS, as it is foreseen that with the removal of the dipole magnet and other in-vacuum parts, less pumping speed is required.

VESPA LABORATORY

The VESPA Mk. 1 test was performed using the FETS ion source area and equipment; the Mk. 2 requires its own working area. Therefore a laboratory has been acquired from the ISIS linac group and converted for ion source use, as shown in Fig. 1. This includes: the erection of a partition wall and removal of a false ceiling to create a safe high voltage enclosure; re-arrangement of lighting and electrical systems; installation of a high voltage platform, and plumbing in of water, hydrogen, nitrogen and compressed air.

Expansion room has been allowed for in the high voltage area. For example, it is planned to perform spectroscopic measurements on a D-Pace volume-type H^- ion source in the future to compare with optical emissions from the surface-type Penning source. The remainder of the laboratory has space for ion source electrical and maintenance work areas.

Figure 1: Ion source equipment in the VESPA high voltage enclosure.

VACUUM VESSEL

Vacuum and High Voltage Testing

The 35 kV insulator is exactly the same design as that used on ISIS. Unfortunately the glass-reinforced Noryl resin historically used is no longer available in the size required for this insulator. Ertacetal-C was chosen as a potential replacement as it has similar electrical, mechanical and low water-retention properties. If long term use of this material on the VESPA is successful, then its availability will be of benefit for ISIS operational spares. The use of only one 2200 L/s turbo-molecular pump, rather two as on ISIS, and the unknown vacuum performance of Ertacetal-C meant vacuum and high voltage tests were required. The insulator was attached to the vessel and all ports blanked off. No signs of high voltage breakdown were seen either with or without vacuum present, and a vacuum helium-leak detector stabilised at 1×10^{-10} mbar L/s, indicating no leaks.

Installation

Figure 2 shows the vessel, soon be installed on a support frame such that the insulator protrudes through a hole in the wall of the high voltage enclosure. The frame will be bolted to the floor and fully enclose the turbo pump, gate valve, backing scroll-pump and all hoses. A water chiller unit and controls rack are positioned next to the frame to minimise hose and cable lengths.

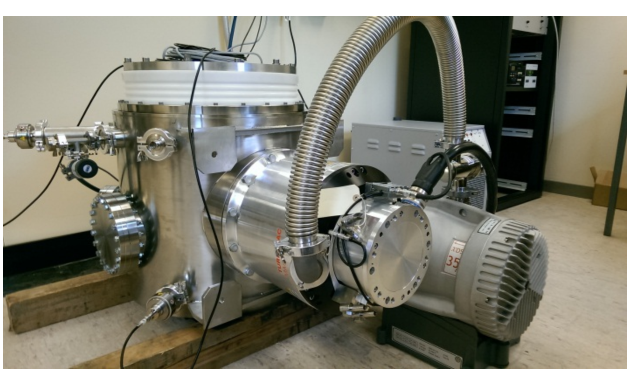

Figure 2: VESPA vacuum vessel undergoing testing.

ION SOURCE

Temperature Control Crate

With the VESPA coming online, five separate ion source facilities can now operate independently at RAL. It is preferable not to use ISIS operational spare ancillary equipment, therefore new ones need constructing. Although requiring significant technician resource, this does present an opportunity to try new solutions. The first new system is a temperature controller crate based on off-the-shelf Omega CNi32 controllers. These allow monitoring, control and remote programming operation in one extremely compact unit, rather than requiring separate circuitry as on the existing ISIS temperature controller crates. Each Omega controller compares a thermocouple reading with a desired temperature set-point and outputs a 0-10 V analog control signal. This signal varies the duty cycle of a pulse applied to the gate of a MOSFET. The MOSFET modulates the current flow to a heating element in the ion source from a compact fixed 2 A, 50 V power supply. There are eight of these temperature control channels available in one crate. This new system is simple, inexpensive and robust to high voltage breakdowns. In addition, extra features are available from the Omega controllers, such as alerting the user if the temperature is outside an acceptable range by changing the digital display colour from green to red.

Mounting Flange and Extraction Optics Design

Figure 3 shows the mechanical design of the ion source mounting flange and extraction electrodes. The mounting flange is re-entrant, ensuring the ion source is positioned inside the vessel in line with the viewports. Even with the ISIS 90° dipole magnet removed, the beam is deflected somewhat by the plasma-confining Penning magnetic field. Tracking simulations show that the source should be tilted 12° and offset downwards by 0.5 mm to counteract this deflection. The puller electrode is mounted on the ion source itself in order to ensure good alignment with the plasma electrode. The remaining post-extraction acceleration and focussing electrodes are fixed to the vessel via alignment dowels. Beam current is measured using a toroid < 100 mm from the plasma electrode.

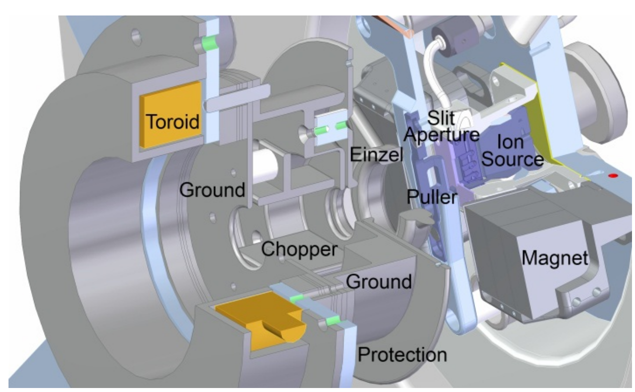

Figure 3: Ion source and extraction electrodes. Source can be mounted flush or tilted, as shown.

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TRACKING STUDIES

The new extraction system incorporates puller, focussing, acceleration and steering/chopping electrodes. It is desirable to separate extraction from acceleration as then the puller electrode can be pulsed and its voltage varied to ensure a perveance match for the required beam current, without affecting the final beam energy. The beam is extracted from a slit aperture in the plasma electrode. Using an einzel lens with an elliptical aperture, the beam is shaped into a round profile. IBSimu [6] was used to optimise the extraction system and perform error studies. The new extraction system is rather tolerant to errors in perveance, source tilt angle and magnetic field strength. This is important as it provides operational flexibility, loosens machining tolerances and allows for deviations in permanent magnet field strength. Figures 4 and 5 show simulation results of the ideal beam, where red are H^- ions, yellow are co-extracted electrons, blue are the electrodes and green are lines of equipotential.

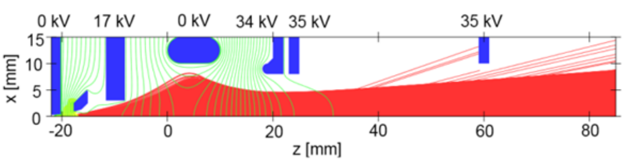

Figure 4: Tracks of simulated particles in the horizontal mid-plane (i.e. in the short dimension of the slit aperture). The large angles seen at z > 40 mm are the 0.5% halo particles which are over-focused by the einzel lens.

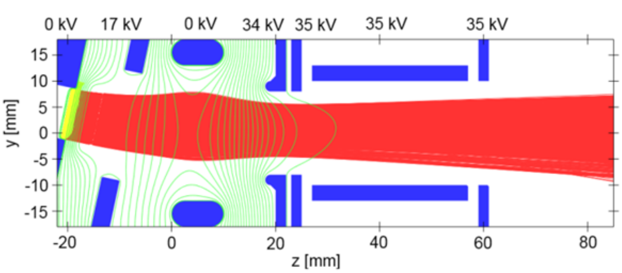

Figure 5: Tracks of simulated particles in the vertical mid-plane (i.e. in the long dimension of the slit aperture). The tilted ion source results in a small beam offset in position and angle of +0.9 mm and -7.3 mrad at the end of the simulation; well within the steering correction range.

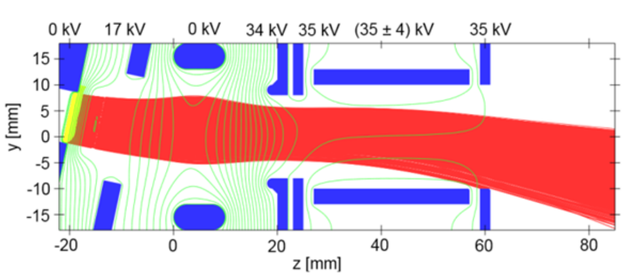

Figure 6: Vertical beam deflection with the chopper plates set to ±4 kV. Taking into account beam divergence, the chopped and unchopped beams will be fully separated approximately 500 mm from the chopper plates.

Chopping and Steering

ISIS runs at lower repetition rates during machine setup and tuning. In practise, it is the ion source puller electrode rep rate which is adjusted as this ensures beam pulses are only presented to the rest of the accelerator when needed. Experience has shown, however, that a prolonged period of running the puller at low rep rates degrades long-term source performance. The VESPA will investigate the possibility of keeping the puller at the normal 50 Hz rep rate whilst using chopping plate electrodes to remove unwanted beam pulses such that the rest of the accelerator operates at low rep rates. Figure 6 shows the beam deflected by over 180 mrad with ±4 kV applied to the chopper plates. Applying a ±500 V zero-offset to the chopping pulses allows the un-chopped beam to be steered up to 50 mrad to correct for minor misalignment or magnetic field errors.

STATUS AND FUTURE PLANS

The vacuum vessel will soon be fixed in place on its support frame and the emittance scanners and optical monochrometer installed. All ion source ancillary equipment is ready except for some minor pieces of the hydrogen control and interlock system. Fibre optics have been installed and tested which transmit the control, timing and measurement signals. The ion source mounting flange and extraction electrodes are in manufacture.

First plasma and beam measurements are expected in August and will be performed on the existing ISIS extraction system without the dipole magnet. This will be the first measurement of the beam actually produced by the ion source. Thereafter, the new extraction optics will be installed and validated.

The removal of the dipole magnet poses caesium trapping challenges, so a surface ionisation detector system is under development to quantify the caesium flux escaping the present and new extraction systems.

Overall, the VESPA is progressing as planned and promises many insights into the ISIS ion source operation, with the anticipation of greatly improved efficiency and performance.

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