

TESTING, INSTALLATION, COMMISSIONING AND FIRST OPERATION OF THE ISIS RFQ PRE-INJECTOR UPGRADE

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Abstract

Situated at the Rutherford Appleton Laboratory (Oxon., UK), ISIS is currently the world's most intense pulse spallation neutron source, delivering 160 kW of 800 MeV protons to a tungsten target at 50 Hz. A major facility upgrade programme involves the construction of a second, 10 Hz target and an increase in the total beam power of up to 50% (i.e. up to 240 kW). To achieve the planned increase in average beam current to 300 μ A whilst maintaining the current manageable levels of beam loss, four 2nd harmonic RF cavities have been installed in the synchrotron and the ageing Cockcroft-Walton pre-injector in the linac has been replaced with a 665 keV, 202.5 MHz, 4-rod Radio Frequency Quadrupole (RFQ). This paper describes the extensive testing, installation, commissioning and successful initial operation of the RFQ pre-injector upgrade.

INTRODUCTION

To help improve overall reliability and allow for planned beam current increases, the original ISIS linac pre-injector has been replaced with an RFQ [1]. The original equipment consisted of a 665 kV Cockcroft-Walton accelerator followed by a low energy drift space (LEDS) with quadrupole triplets, diagnostics and a coaxial buncher cavity (see Fig. 1).



Figure 1: Left, Cockcroft-Walton accelerator, Right, low energy drift space.

The replacement pre-injector uses the existing, highly reliable Penning H^- ion source mounted on a 35 kV accelerating column [2] and followed by a 3 solenoid magnetic low energy beam transport (LEBT) and 202.5 MHz, 4-rod RFQ, designed in collaboration between IAP Frankfurt University and RAL. So as to allow installation without fully decommissioning the Cockcroft-Walton, the entire new pre-injector was designed to fit into the ~ 3 m long space provided by removing the LEDS only.

In order to fully characterise the beam and long-term soak test the new pre-injector systems, an RFQ test facility was constructed in building R8 at RAL [3]. The test facility implemented every system which would

eventually be installed onto ISIS including controls and machine and personnel interlocks.

RF CONDITIONING

The RFQ was delivered to RAL in the summer of 1999 and, following commissioning of the vacuum and water systems, RF conditioning of the cavity started in December of that year [4]. An X-ray end point measuring system was used to determine the correct 90 kV electrode voltage by monitoring the bremsstrahlung from the cavity [5].

Although initial conditioning proceeded rapidly, considerable sparking and vacuum pressure rises occurred as full field level was approached. Eventually full field was achieved with manageable levels of sparking and work proceeded with commissioning the rest of the test facility. In 2002, following more than 2000 hours of operation during which an extensive experimental programme was completed, the spark rate began to increase until in late 2002 operation at full field level was no longer possible. Visual inspection of the RFQ electrodes through a window on the cavity showed extensive discolouration of the electrode surfaces and considerable spark damage. A decision was taken to dismantle the RFQ to clean and polish the electrodes, an opportunity afforded to us by the simplicity of the 4-rod design with its removable electrode insert (see Fig. 2).

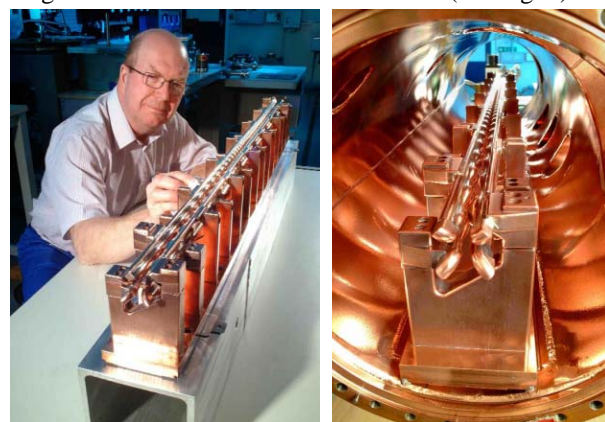


Figure 2: Left, the electrode insert undergoing final polishing, Right, the insert reassembled into the cavity.

Following reassembly and reinstallation in the test facility, an in-situ bake was performed by applying ~ 200 W of CW RF with the cooling water switched off. The electrode temperature was monitored with a pyrometer via an infrared transparent window and rose to 70 – 80 C accompanied by a vacuum pressure rise from 1×10^{-7} to 1×10^{-6} mbar. Only when the hot pressure had returned to 1×10^{-7} mbar, after ~ 6 hours, was the RFQ

allowed to cool, the water switched back on and high power pulsed conditioning started. From first pulse to full field level at nominal duty factor, the conditioning took only 8 hours with almost no sparking and only moderate vacuum pressure rises. Since then in excess of 6000 hours of full duty factor RF have been run with no degradation of the RF performance or deterioration of the state of the electrodes.

The X-ray dose rate 0.5 m from the cavity fell by two orders of magnitude from 5 mSv/hr measured shortly after initial conditioning to 50 μ Sv/hr measured following cleaning.

BEAM TESTS

In addition to soak testing to demonstrate long term reliability, the test facility allowed an extensive experimental programme to be undertaken to verify the main beam parameters.

LEBT

Due to the severe length constraint on the new pre-injector [6], the restricted solenoid length imposed a maximum beam pipe radius with the result that non-negligible beam loss occurs in the LEBT. Fortunately the ion source provides sufficient current that in excess of 30 mA can still be successfully matched into the RFQ [2]. Emittance measurements [7] in the LEBT demonstrated the ability of the solenoids to equalise the asymmetric emittances produced by the ion source and showed rms values close to the RFQ design emittance of 0.5π mm mrad normalised [8]. See Fig. 3.

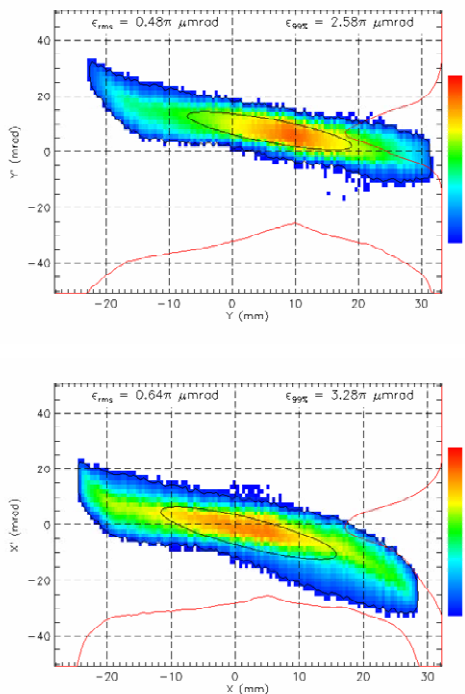


Figure 3: Emittances in the LEBT. Top, vertical 0.48π mm mrad rms, bottom, horizontal 0.64π mm mrad rms

RFQ Transmission

Beam transmission through the RFQ was measured using current transformers built into the end flanges of the RFQ vessel. In order to distinguish total transmission from the trapped and accelerated beam, an electrostatic energy separator was used [9]. At full field level, 95% transmission was achieved for beam currents in the range 30 – 40 mA. Transmission as a function of various parameters was measured and showed good agreement with computer simulation [8]. Fig. 4 shows an example of beam transmission as a function of electrode voltage.

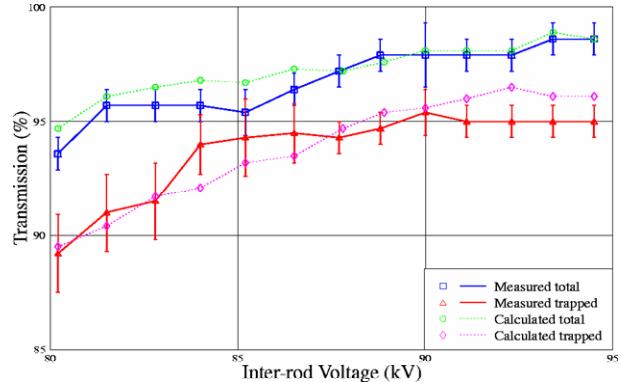


Figure 4: Measured total transmission (blue), measured trapped transmission (red), calculated total transmission (green) and calculated trapped transmission (magenta) as a function of electrode voltage.

Beam Energy

The RFQ output beam energy and energy spread was measured using a gas scattering energy analyser [10]. Fig. 5 shows the output beam energy spectrum for 30 mA beam current and 90 kV electrode voltage. Again the agreement with calculations is rather good.

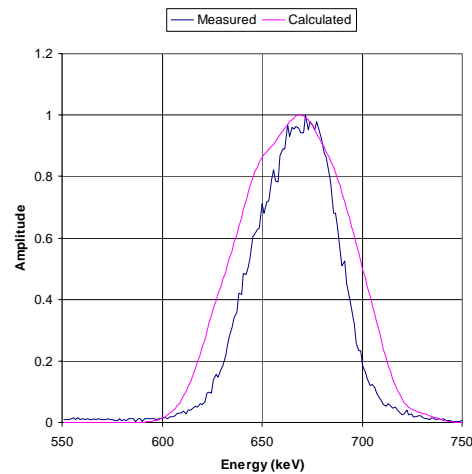


Figure 5: Measured and calculated output energy spectrum for 30 mA beam current and 90 kV electrode voltage.

Bunch Length

The bunch length at the output of the RFQ was measured using a coaxial fast Faraday cup. The Faraday

cup could be positioned at various distances downstream of the RFQ output in order to measure the rate of debunching of the beam. Measurement of the bunch length at different electrode voltages showed good agreement with simulation. Fig. 6 shows an example of the RFQ beam debunching.

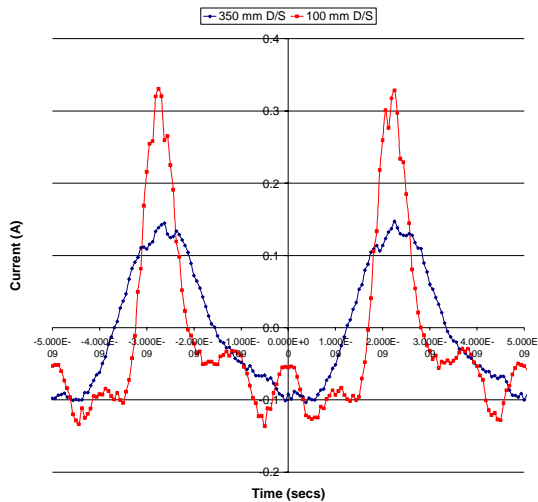


Figure 6: Measured bunch length 100 mm downstream (red) and 350 mm downstream (blue) of the RFQ for a 30 mA beam.

The energy and bunch length measurements indicated that the beam was within the longitudinal acceptance of the first DTL tank of the ISIS linac.

Output Emittance

Beam emittances were measured at the output of the RFQ [8]. For a well matched beam at the RFQ input, there was no observed increase in the rms emittances in the RFQ. The phase space orientation was close to that predicted by calculation.

INSTALLATION AND COMMISSIONING

Installation of the new pre-injector onto the ISIS linac was scheduled for a 6 month maintenance shutdown beginning in April 2004. Because this period was not sufficient to install all of the new systems and equipment, a considerable amount of preparation and installation of the infrastructure had been completed during shorter maintenance periods over the preceding two years.

The installation proceeded smoothly and was completed on time. Due to the extensive testing and commissioning carried out on the test facility, all components were found to work as expected with no surprises at all during installation. Fig. 7 shows the new pre-injector installed on the ISIS linac.

Because every component had been run for in excess of 2000 hours on the test facility, when it came to commission the pre-injector everything went extremely smoothly. All equipment had been powered without beam for several weeks before completion of other work on the accelerator allowed a 70 MeV beam to be accelerated. It

took ~30 minutes from first opening the beam-stop to establishing a 19 mA, 70 MeV beam, the same or slightly more current than achieved with the old pre-injector. Following further optimisation of the pre-injector and linac, currents up to 24 mA at 70 MeV have been achieved. It is hoped that up to 30 mA may be achieved by changing the polarity of several quadrupoles in the first DTL tank.

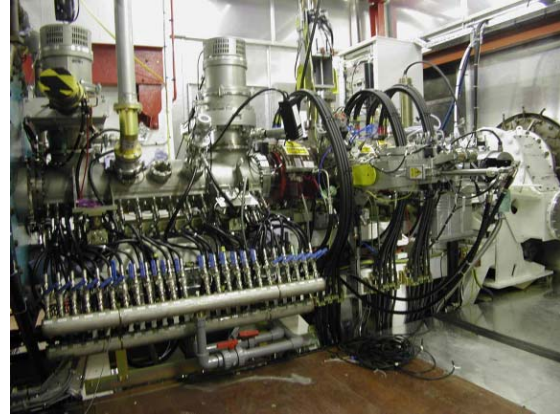


Figure 7: The RFQ pre-injector installed in what was previously the LEDS area of the ISIS linac.

OPERATIONAL EXPERIENCE

Since installation the new pre-injector has operated in excess of 5000 hours with high reliability. No significant lost time has been due to the new pre-injector, a remarkable achievement for such a significant upgrade. There is no indication that the RF performance of the RFQ has deteriorated since it was cleaned.

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