MEASURED PERFORMANCE OF THE ISIS RFQ

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Abstract

The ISIS RFQ is a 665 keV, 202.5 MHz, 4-rod RFQ intended as a replacement pre-injector for the ISIS spallation neutron source at RAL. A test facility has been constructed for soak testing and characterising of the RFQ before installation. Results are presented for measurements of the principal parameters of the RFQ together with its performance characteristics. A comparison is made between the measurements and the results from computer simulations.

1 THE ISIS RFQ TEST FACILITY

The RFQ test facility is described in detail in [1][2]. An ISIS Penning ion source [3][4][5] produces a 30 mA beam of 35 keV H-minus ions which are matched into the RFQ by a three solenoid magnetic low energy beam transport (LEBT)[6][7]. A 202.5 MHz 4-rod RFQ [8][9] accelerates the beam to 665 keV using ~200 kW of RF power. Toroidal beam current transformers (BCTs) are installed at the ion source output and RFQ input at 35 keV as well as at the output and ~1m downstream of the RFQ at 665 keV. Time resolved emittance measurements are made using slit and cup scanners [10] upstream and downstream of the RFQ. A gas scattering energy analyser [11][12] is installed in an external beamline. Diagnostics soon to be installed include a magnetic spectrometer and a coaxial fast Faraday cup for bunch length investigations.

2 INPUT MATCHING

Due to the very high gas load of hydrogen from the ion source, the LEBT was initially set up with small aperture restrictions in the beam path at the ion source output and also at the RFQ input to ensure good vacuum in both the LEBT and RFQ. With this arrangement a beam current of 24 mA could be matched into the RFQ for an ion source current of 36 mA, a LEBT transmission of only 67%. Figures 1 & 2 show emittance measurements of the beam between the second and third solenoids with the gas flow restrictions in place. The RMS normalised emittances are ε_H = 0.19 π μm.rad and ε_V = 0.22 π μm.rad. Analysis of the LEBT optics based on these measurements suggested that beam was being lost on the restrictions. Removal of the ion source restriction increased the source current to 50mA but the RFQ input current only increased to 34 mA, a LEBT transmission of still only 68% due to increased stripping losses resulting from the higher vacuum pressure. The addition of a further 500 l/s turbo drag pump to the LEBT reduced the pressure by a factor of ~3 to 1.1×10^{-5} mbar and has allowed beam currents as high as 40 mA to be matched into the RFQ, a LEBT transmission of up to 80%.

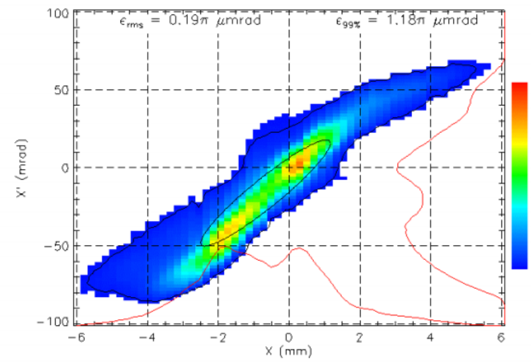

Figure 1: Horizontal phase space in LEBT at 35 keV. Gas flow restrictions in place.

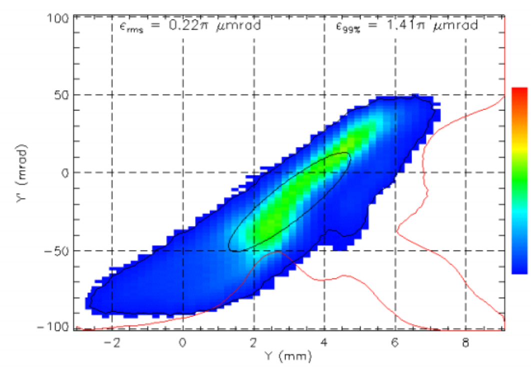

Figure 2: Vertical phase space in LEBT at 35 keV. Gas flow restrictions in place.

Figures 3 & 4 show the emittance in the LEBT with the gas flow restriction removed. The RMS normalised emittances are ε_H = 0.64 π μm.rad and ε_V = 0.48 π μm.rad. Note that Figs 3 & 4 correspond to different solenoid settings than Figs 1 & 2. The increase in the RMS emittances which accompanies the increase in beam current suggests that although much of the charge is contained within a small emittance, there is significant low density beam out to large radii. Some additional emittance increase may occur due to aberrations in the solenoid fields. Initial results from the ISIS ion source development rig tend to confirm these conclusions [5].

The best RFQ match, resulting in an RFQ transmission of >95%, gives a LEBT transmission of only ~70%. The loss comes from a combination of stripping in the background gas and collisions with the beam pipe. A higher transmission in the LEBT of up to 80% can be achieved at the expense of the quality of match into the RFQ. For this slightly mis-matched condition the RFQ transmission is only 90%. Although this is still an acceptable level of transmission, the input mis-match needs to be kept low to prevent emittance increase at the RFQ output.

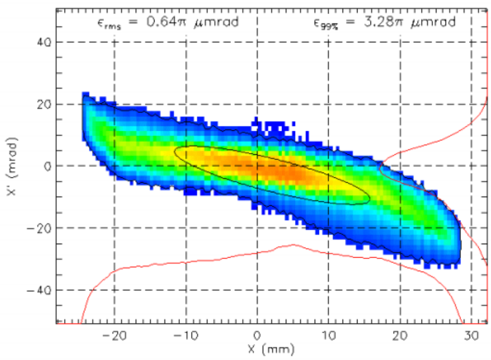

Figure 3: Horizontal phase space in LEBT at 35 keV. Gas flow restriction removed.

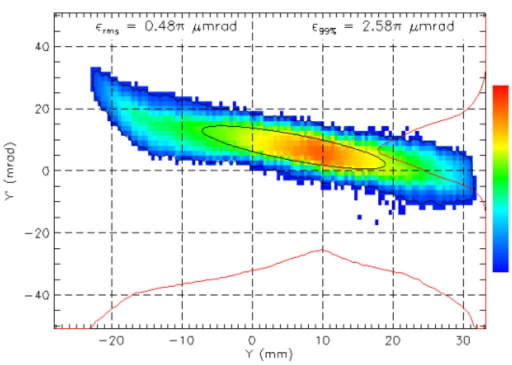

Figure 4: Vertical phase space in LEBT at 35 keV. Gas flow restriction removed.

Computer tracking of the beam from Figs 3 & 4 through the final solenoid field for the empirically found best match is in very good agreement with the calculated input match for the RFQ. All the measurements so far indicate that at least 95% space charge neutralisation occurs in the LEBT.

3 RFQ TRANSMISSION

In order to determine the correct level of RF power needed to achieve the design electrode voltage of 90 kV, an X-ray end point measurement system has been commissioned in the test facility [13]. The results of these measurements together with improved power level monitoring indicate a power of 192 ±2 kW is required without beam. This is less than previously calculated [2].

Due to the strong focussing in the RFQ, some beam, which is not trapped in the RF bucket and therefore not fully accelerated, still exits the RFQ. This untrapped beam will be measured by the RFQ output BCT so in order to measure the fraction of trapped/untrapped beam another BCT is located ~1m downstream of the RFQ with an electrostatic energy discriminator placed between them [14].

Figure 5 shows the RFQ measured transmission efficiency for the total and trapped beam over a range of electrode voltages from 80-95 kV. Also shown are the calculated transmission efficiencies for the same conditions.

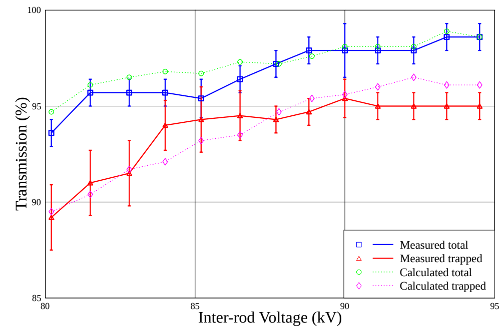

Figure 5: Measured and calculated RFQ transmission efficiencies for total and trapped beam as a function of electrode voltage.

Figure 6 shows the RFQ measured and calculated transmission efficiency for the total and trapped beam over a range of input energies from 30-40 keV. The design value is 35 keV.

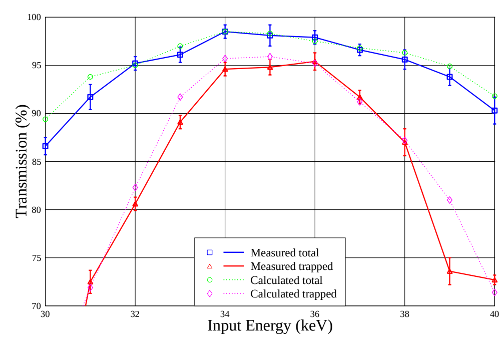

Figure 6: Measured and calculated RFQ transmission efficiencies for total and trapped beam as a function of input energy.

It is evident from Figs 5 & 6 that there is very good agreement between the measurements and the computer simulations.

4 FINAL ENERGY

The final beam energy has been measured using a gas scattering energy analysis system [11][12]. This system measures the total kinetic energy of the beam, including any transverse components, using xenon gas cells to attenuate the beam and a silicon particle detector to measure the energy of the particles. Table 1 summarises the measured and calculated peak total beam energy for several electrode voltages. Conversion electrons from a 2kBq Cs-137 source are used to calibrate the system.

Table 1: Total kinetic energy of RFQ output beam for several electrode voltages. All energies are ±1 keV

Electrode Voltage	Measured Peak Energy	Calculated Peak Energy
80 kV	661 keV	661 keV
85 kV	665 keV	663 keV
90 kV	670 keV	669 keV

5 OUTPUT EMITTANCE

The RFQ output emittances are measured at 665 keV ~0.5m downstream of the RFQ output. Figures 7 & 8 show the measured and calculated (matched) horizontal and vertical phase spaces respectively. The emittance asymmetry is most likely attributable to a vertically mis-steered input beam.

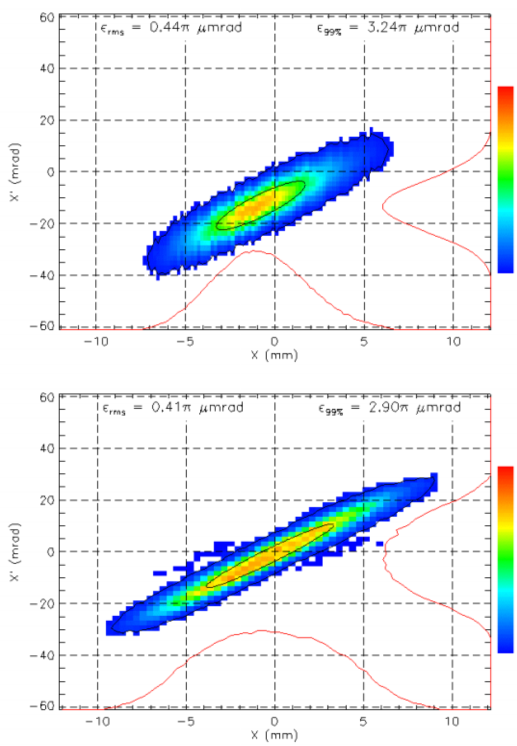

Figure 7: RFQ horizontal output phase space. Top: measured, ε_H = 0.44 π μm.rad rms, Bottom: calculated

6 CONCLUSIONS

Of the measurements made so far at the ISIS RFQ test facility, all are in good agreement with the design calculations. This verifies the performance of the design and simulation codes and gives confidence in their use for future more demanding applications such as an RFQ for the European Spallation Source (ESS) project.

7 REFERENCES

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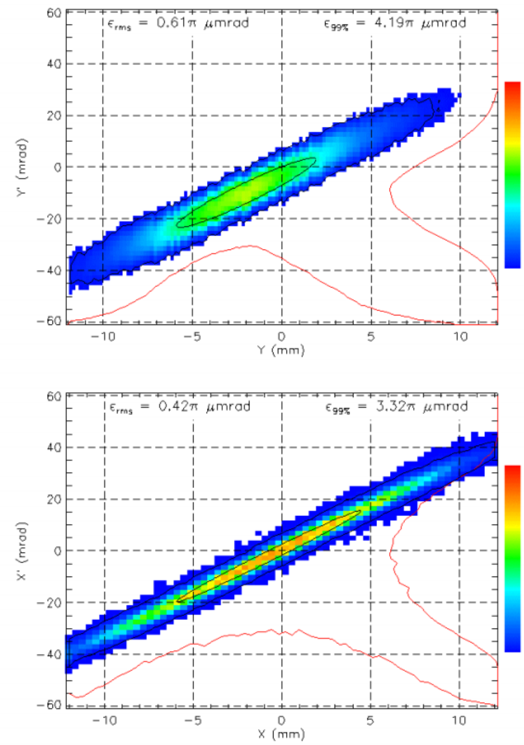

Figure 8: RFQ vertical output phase space. Top: measured, ε_V = 0.61 π μm.rad rms, Bottom: calculated

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