IMPROVED RESULTS FROM THE GAS SCATTERING ENERGY SPECTROMETER ON THE ISIS RFQ TEST STAND

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Abstract

The novel Gas Scattering Energy Spectrometer on the ISIS RFQ Test Stand at the Rutherford Appleton Laboratory (Oxfordshire, UK) has been used to measure the energy spectrum of the ~665 keV H^- beam from a four-rod RFQ as a function of RF drive power. Since EPAC'02 changes have been made to the experimental arrangement, which markedly improve the quality of the results that can be obtained. These new results are reported.

1 THE APPARATUS

The purpose of the Gas Scattering Energy Spectrometer (GSES) is to confirm the mean energy and energy spread of the nominal 665 keV beam from the ISIS RFQ. This RFQ, after comprehensive testing, is intended to replace the existing Cockcroft-Walton pre-injector on the ISIS spallation neutron source at the Rutherford Appleton Laboratory (RAL). The four-rod RFQ performs well, and is able to transport more than its design current of 30 mA at less than its nominal design RF power of 210 kW.

A more detailed description of the design process for the apparatus used can be found at [1]. Its basis is a set of two cascaded assemblies each consisting of a 130 mm long gas scattering cell, a 0.5 m drift length and three small (~0.2 mm diameter) apertures, which together reduce the peak intensity of the beam current sufficiently to allow a semiconductor charged particle detector [2] to be used to detect individual H^- ions and measure their energies. The total drift length between RFQ exit and detector is ~6 m. Xenon gas (at low pressure) is used to scatter the H^- beam because the higher the atomic number of the scatterer the lower is the energy loss for a given mean multiple scattering angle. The energy loss caused by the xenon is calculated for the relevant scattering thicknesses used and is added back in as a small correction to the measured energies.

The particle detector used was an Ortec® BA-025-025-1500 silicon surface barrier detector with an active area of 25 mm² and a depletion depth of 1.5 mm, and was operated at a bias voltage of 186 V. Signals from the detector pass first through an EG&G Ortec® [2] Model 1421H pre-amplifier and then into a Canberra® Model 2020 spectroscopy amplifier with 1 μs pulse shaping. The bipolar output from the amplifier is passed into a TRUMP PCI-8k multi-channel analyser PC card. Ortec® Maestro-32 spectrum analysis software is used to visualise and analyse the resultant spectra. Before taking a measurement the system is calibrated by fitting gaussians to the 624 and 656 keV lines from a 2kBq Cs-137 conversion electron source which is installed in the detector box on a movable arm. After calibration the bias voltage is never changed.

In the present measurements the X-ray background has been greatly reduced. In the previous measurements reported in [3], X-rays produced between the rods within the RFQ vessel were able to reach the surface barrier H^- particle detector by propagating down the beam pipe, and the addition of the resultant noise to the H^- pulses from the particle detector had the effect of broadening the measured energy spectrum. In the present measurements a 4mm thick tantalum disc was introduced to attenuate the X-rays (maximum photon energy 90 keV corresponding to the peak-to-peak rod-to-rod RF voltage of 90 kV). A hole of 0.5 mm diameter, the minimum diameter practicable, was drilled through the tantalum disc, and the tantalum disc was then glued to the front of the aluminium disc in the final bellows before the diagnostic box so that the hole in the tantalum disc lined up with the ~0.2 mm diameter hole in the aluminium disc. Although a thickness of 4 mm of tantalum is able to block effectively all the X-rays [4] some are still able to reach the detector through the central hole, but overall the X-ray flux on the detector is reduced by a factor ~250.

A further improvement made in the present experimental system was the application of a 285 μs gating pulse to the multi-channel analyser to eliminate interference spikes at the beginnings and ends of the

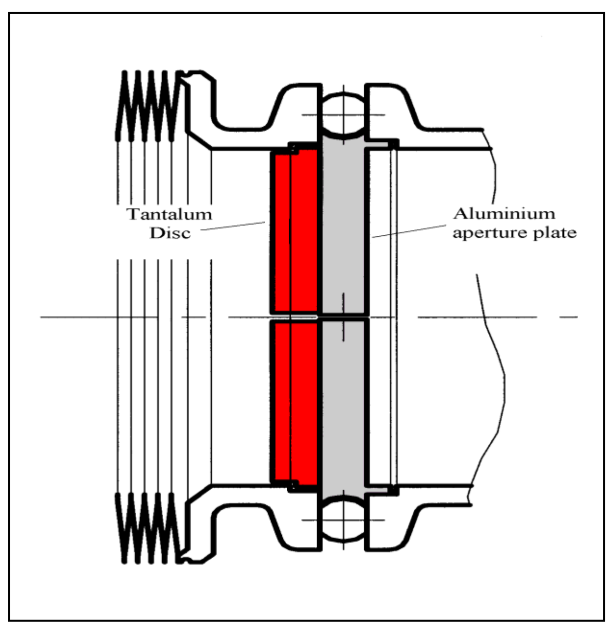

Fig. 1: The new tantalum disc attached to the aperture plate

pulses of RF driving the RFQ. Conversion electron calibration runs were performed while gating only during the RF pulse, and the standard deviations of the two caesium peaks measured as 4.7±0.4 keV compared with 5.1±0.1 keV gating *outside* the RF. Therefore there seems to be no significant residual widening effect from the X-rays.

2 DATA ANALYSIS

The measured spectra of energies of H^- particles from the RFQ should be corrected for the following effects: background, energy losses in the xenon gas, energy straggling in the xenon gas, and finite resolution of the surface barrier detector.

Background was first removed from the present measurements by subtracting from the H^- spectrum channels the average value of 400 channels well above the H^- peak in energy. Next, three sets of cubic splines were fitted to the data to represent plausibly smoothly the data and $\pm 2\sigma$ error limits. The resolution function of the surface barrier detector (given by the shape of the Cs-137 conversion electron lines as described above) was then deconvolved from the data by taking the best fit spline set, convoluting it with a gaussian of standard deviation 5.1 keV representing the resolution function (FWHM 12.0 keV) of the surface barrier detector, and adjusting the height of each channel until the convolution of the resolution function and the corrected spectrum function best fitted the measured spectrum data. Then the energy loss of the H^- particles in the xenon, only ~1.8 keV for the gas pressures typically used, was added back on the basis of polynomial interpolation amongst tabulated values of proton stopping power in xenon as a function of proton energy [5]. The energy straggling in the xenon [6] was estimated at typically only 2×10^{-2} keV, and so was neglected. Finally, from the corrected spectra of H^- particles from the RFQ were calculated mean energies and RMS widths, both for spectra truncated at energies corresponding to the full width tenth maximum points and for the entire spectra (including the asymmetric low and high energy tails). The mean energies for the whole distributions were consistently lower than those for the truncated distributions (Fig 3.). This confirms the previous finding that the low energy tail is larger than the high energy one.

The corrected measured results have been compared with computational particle tracking simulations of the RFQ. Performing this comparison is useful both to verify the RFQ codes and to confirm that the RFQ is performing as expected/predicted. Due to the long drift length between RFQ and detector, and the high space charge forces in the RFQ bunches, the beam has completely debunched by the time it reaches the detector. The high space charge also affects the energy spectrum of the beam, widening the energy spread. Therefore, in order to compare like with like, the measured and simulated energies and widths are compared at the position of the detector.

One effect not included in the calculation above is that of stripping of H^- ions in xenon. It has been previously calculated that at the pressures used in this experiment, almost all the H^- ions should be stripped to H^+. Therefore the two electrons will carry off some small fraction of the H^- particles' energy. This fraction may be $\sim 2{*}m_ec^2/ m_pc^2$, i.e. ~1/918. Assuming a mean energy of 665 keV, this effect would add at most 0.72 keV to the energies quoted below for protons.

3 RESULTS AND DISCUSSION

The following graphs summarise some of the results obtained in the experiments reported above:

Figure 2 shows one example of the spectra obtained. The blue curve represents the original raw data. The red curve represents the same data after correction for energy loss in the xenon, detector resolution and background.

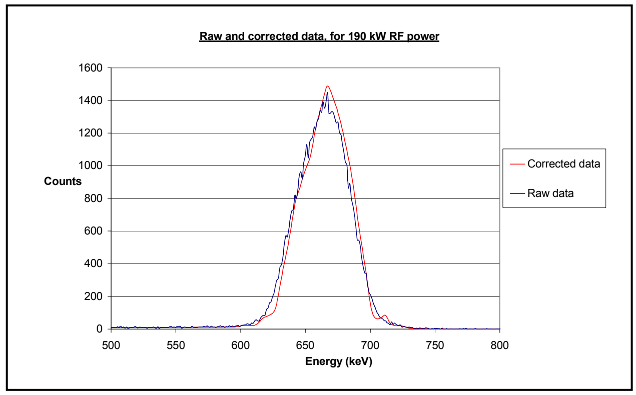

Fig. 2: Raw and corrected spectrum data, for an RF power of 190 kW

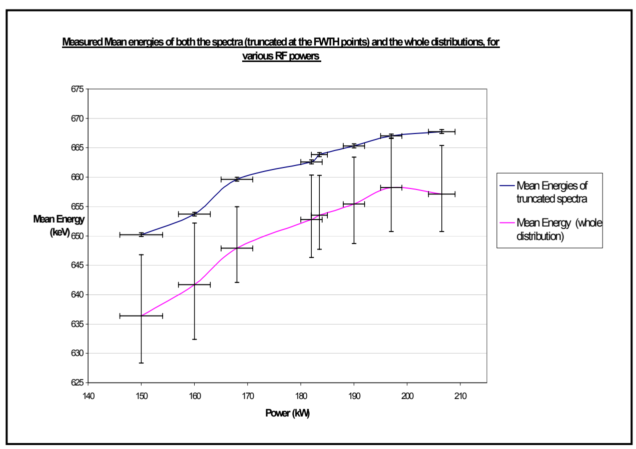

Fig. 3: Comparison of mean energies of truncated and untruncated spectra

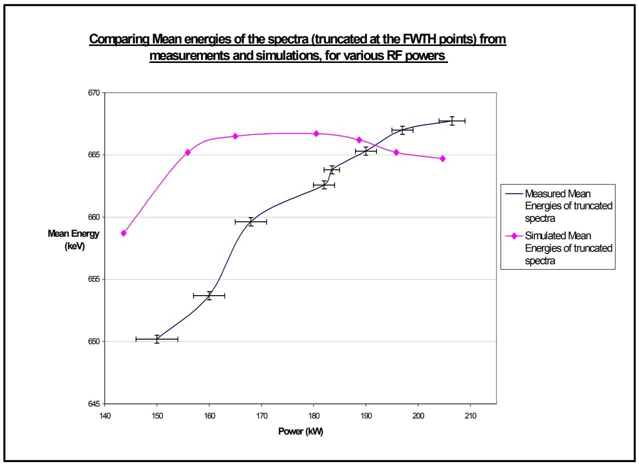

Fig. 4: Comparison of Measured and Simulated mean energies, for the truncated spectra, for various RF powers

At no RF powers do the simulated mean energies differ from the measured mean energies (for the truncated spectra) by more than 1.7% (Fig. 4). The small remaining differences between them could be partly due to the fact that the GSES by its very design selects only the central portion of the beam, whereas in order to provide sufficiently good statistics, the simulated figures are calculated by including particles with a larger range of angles. The measured mean energies generally rise with RF Power. However, the difference in RF power dependence of the mean energies between the measured and simulated results is as yet not understood.

At powers well below the design RFQ operating power, i.e. < ~170 kW, the measured distributions become more asymmetric, with the lower energy tail becoming a greater proportion of the whole, and the central peak becoming consequently narrower. This is indicative of the reduction of the size of the RF bucket and the large phase oscillations which occur at lower powers.

As can be seen from Fig. 5, the measured RMS widths for the truncated spectra are fairly constant at 16.5 keV above about 165 kW, about 14 keV below this RF power, and compare well with the simulated values. The tracking simulations indicate that the space charge after the RFQ exit acts to increase the energy spread of the beam by several keV.

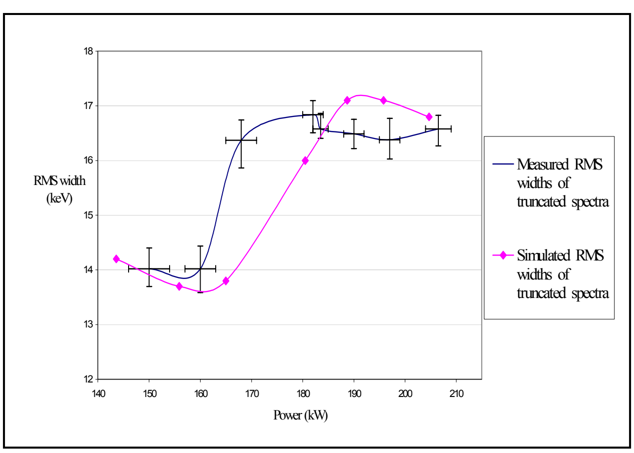

Fig. 5: Comparison of Measured and Simulated RMS widths, for the truncated spectra, for various RF powers

4 CONCLUSIONS

The Gas Scattering Energy Spectrometer has been used successfully to re-measure energy spectra from the ISIS RFQ. The improvements made to the experimental arrangement have substantially improved the quality of the data. The results indicate that the beam from the RFQ is consistent with the longitudinal acceptance of the 70 MeV linac intended to be fed by the RFQ.

5 REFERENCES

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