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Space and Time Resolved Doppler Spectroscopy of Neutral Beams

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1. INTRODUCTION

Doppler shifted Balmer-α light emission originating from collisions of neutral hydrogen beams with residual gas molecules is a method commonly used to measure species composition of hydrogen ions (H^+, H_2^+ and H_3^+) extracted from high power ion sources [1-3]. Species composition is derived from the ratio of emission intensities corresponding to full, half and third energy fractions, while the width of the emission lines provides information on beam divergence.

Light is usually collected from a region close to the beam centre line, focused on a single optical fibre and transported to optical monochromator. Parameters determined in this way reflect the average values integrated across the beam along the single line of sight. A new multichannel Balmer-α diagnostic was recently commissioned at JET Neutral Beam Test Bed, which allows spatially resolved measurements of various beam parameters.

2. INSTRUMENT

Light emission from the beam interaction with the residual hydrogen (deuterium) gas is observed close to the exit of the second stage neutraliser (2.26m from the extraction electrodes). Emitted light is focused on a vertical array of optical fibres and transported using 15 fibre links (50m long, 600μm diameter) to the optical bench in the Neutral Beam Test Bed control room and focused again on the entrance slit of a 0.5m visible light monochromator.

The lens-fibre combination determines the observation region of the diagnostic: 15 circular area of 10 mm diameter with 32 mm displacement along the vertical beam axis. The angle of observation is ~46° with respect to the beam centre line allowing Doppler shifted spectroscopy.

The monochromator is equipped with a CCD array detector (600_400 pixels) which enables simultaneous acquisition of up to 15 spectra (Fig. 1a). Vertical axis of the light emission image represents position, and horizontal axis represents the wavelength (370 pixels = 8.2nm). Light emission images are converted into spectra (Fig. 1b), which are then used to determine various beam parameters.

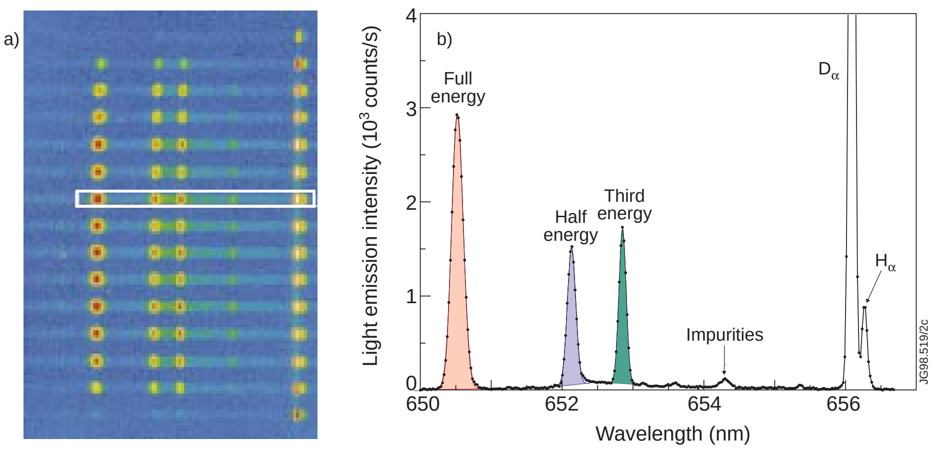

Figure 1. Beam emission image (Balmer-α region) showing 15 spectra (a), and spectrum corresponding to the area close to the beam centre line (b) of a 142kV 30A Deuterium beam at perveance match.

Apart from 15 optical fibres used to measure light emission along the vertical beam axis, additional fibre-lens pairs are mounted at several viewports of the Neutral Beam Test Bed to allow measurement of beam parameters at various locations along the beam centre line. In total, 24 fibres are connected to the optical switchboard in the Test Bed control room and 15 of them can be connected simultaneously to the monochromator providing the means for different experimental scenarios.

3. RESULTS

The high signal intensity, combined with high signal-to-noise ratio, relatively high resolution and well defined geometry enabled us to carry out various experiments using this new diagnostic:

- Spatially resolved measurements of extracted ion species composition and beam divergence from the areas and line widths of Doppler shifted Balmer lines;
- Measurement of the beam steering from vertical beam profiles;
- Time resolved measurements of species mix and beam divergence at one fixed position;
- Measurements of hydrogen isotope exchange in beamline components from the ratio of unshifted D_α and H_α lines (Fig. 1b);
- Measurement of beam power losses caused by charge changing collisions in the accelerator region from the asymmetry of Balmer lines.

Two experiments dealing with plasma source uniformity and with charge changing collisions inside the PINI accelerator are briefly discussed bellow.

3.1. PINI Ion Source Uniformity

The multi-channel H_α spectroscopy confirmed the suspicion that the plasma source used in the JET PINIs has larger plasma non-uniformity than previously assumed. During the development of the plasma sources the uniformity was measured with Langmuir probes inserted into the source [4]. The measurements were undertaken without beam extraction and showed the non-uniformity to be less than 10% overall.

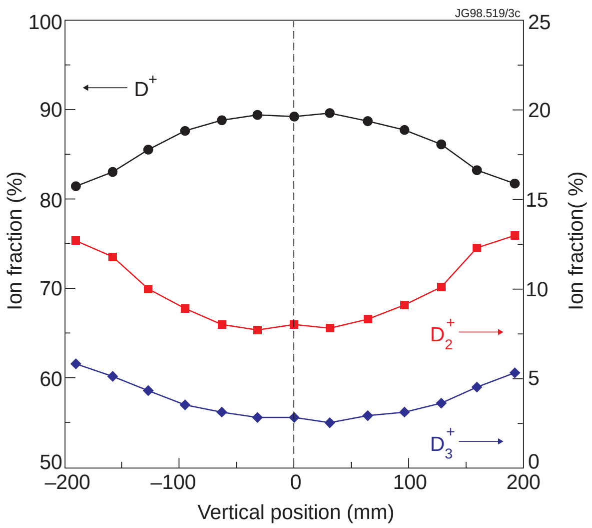

Figure 2. Species fractions for a high current tetrode PINI as a function of vertical position.

Figure 2 shows three ion species fractions as a function of vertical position for a 72kV, 45A deuterium beam at optimum perveance. Although species fraction vary considerably with position, the average values of 86%, 10%

and 4%, for D^+, D_2^+ and D_3^+ respectively, are in excellent agreement with previously measured values using one line of sight in the vertical plane.

Another clear indication of ion source non-uniformity is the variation of optimum perveance with vertical position. Optimum perveance corresponds to a minimum beam divergence and its variation with vertical position for the full, half and third energy component of a 72kV deuterium beam is shown in Figure 3. Dotted line in Figure 3 indicates the average optimum perveance for the full energy component (2.24_10^{-6} A/V$^{3/2}$). This value is in excellent agreement with the optimum perveance derived from calorimetric beam profile measurements: 2.26_10^{-6} A/V$^{3/2}$ (Figure 4.)

The ion source non-uniformity is probably caused by the magnet filter field in the plasma source which was designed to increase the full energy component of the beam [4]. By modifying the volume of the plasma source and the strength and location of the filter field magnets it should be possible to reduce the source non-uniformity further. This would result in a higher beam transmission into the JET plasma and a reduced loading of the beam confining scrapers.

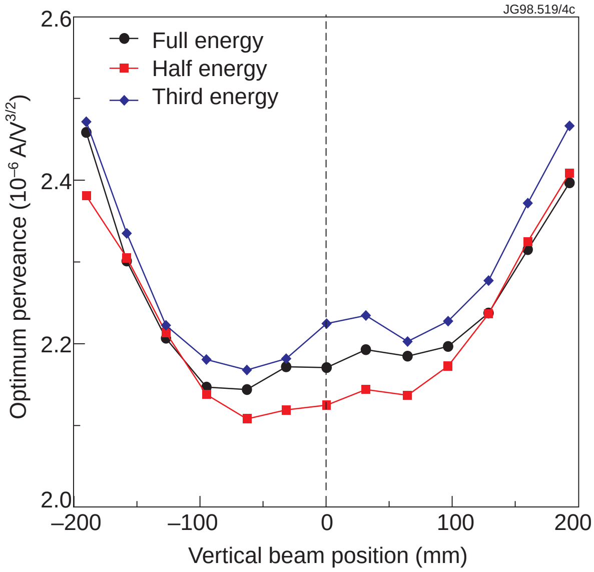

Figure 3. Variation of the optimum perveance with vertical position.

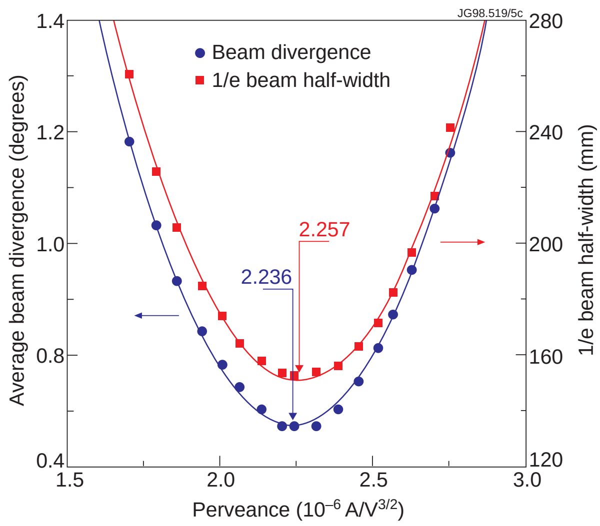

Figure 4. Perveance scan for a 72kV deuterium beam extracted from a high current tetrode PINI.

3.2. Charge Changing Collisions In The PINI Accelerator

During routine spectroscopy measurements we found that projectile emission lines become asymmetric at higher ion source pressures (Figure 5). In addition, the beam emission spectrum shows a non-zero signal in the spectral region between half energy and third energy peaks, which is also related to the ion source pressure. These two features of the beam emission spectra can be attributed to the charge changing collision processes inside the PINI accelerator.

A series of measurements of beam emission spectra was recorded using only one channel of the multi-channel Balmer-α spectrometer. Most of the beam parameters were maintained constant (acceleration voltage ~72 kV, extracted current ~46 A, neutraliser flow ~14 mbar l/s, beam on time 6 s), with the ion source gas flow being the only variable parameter. The analysis of the emission line profiles was performed in the following way. It was assumed that the lower wavelength side (i.e. higher energy) of the emission profile represents the "true" spectral line profile (Figure 5) since ions cannot be accelerated to an energy higher than the total acceleration energy. A least square Gaussian fit was applied using only the lower wavelength half of the spectral line. By subtracting the fit from the measurement a difference spectrum is derived which exhibits a peak shifted towards lower acceleration energies. This light emission is attributed to beam particles which were not accelerated to the full acceleration voltage, i.e. the ions which were either neutralised before gaining the full energy or which were created inside the accelerator region. Similar fitting procedure can also be applied to the spectral region corresponding to the fractional energy particles.

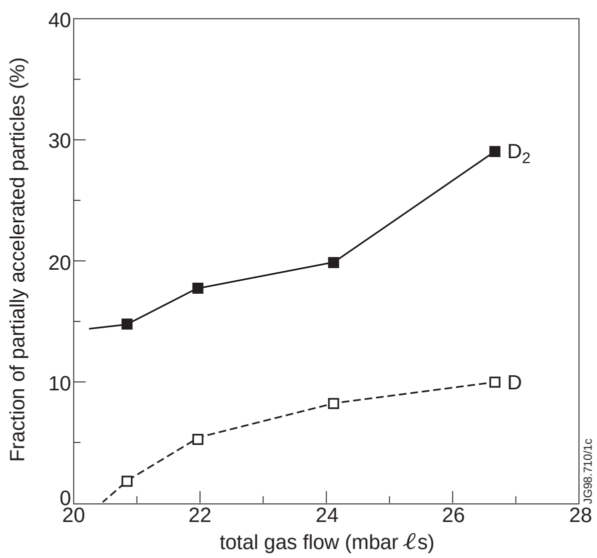

Fig.5. Full energy emission line for the total gas flow of ~27 mbar l/s.

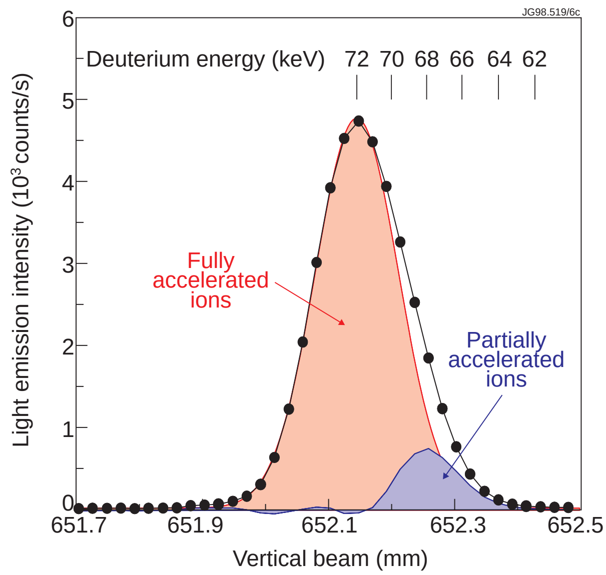

Fig.6. Variation of the fraction of partially accelerated particles with total gas flow.

By comparing the area below difference spectrum peak to the total peak area we can determine the fraction of partially accelerated beam particles. This value is plotted as function of total gas flow (ion source + neutraliser) in Figure 6. We find that, in the considered gas flow range, up to 10% of full energy beam particles and up to 30% of half energy particles are not accelerated to the full acceleration voltage. It should be noted that the nominal total gas flow for JET PINIs is ~25 mbar l/s which is within the range shown in Figure 6. Similar figures for the fractions of partially accelerated particles can be derived from the cross-sections for various charge changing collisions and residual gas density.

There are several important implications of charge changing collisions in the accelerator region. Firstly, a fraction of the beam power is lost due to the effective reduction of the beam energy. At the same time the power loading on downstream beamline component is increased by 20-30%. Finally, the presence of partially accelerated neutrals in the neutral beam injected into torus can considerably influence the interpretation of the JET charge exchange diagnostic data.

REFERENCES

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