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1. INTRODUCTION

Future magnetic-confinement devices which produce significant power by the fusion of D-T nuclei will require an adequate removal rate of helium ash from the plasma core, in order to maintain core purity and the level of power production[1]. Hence, the role of the divertor in removing helium is of crucial importance. At JET, several divertor configurations have been studied to characterise their efficacy at this task, under various operating conditions[2].

More recently, a number of plasmas have been produced with high concentrations of He, up to 100%, to study their characteristics. Such plasmas are seen as relevant to ITER during its early phase of operation, where there are concerns about keeping activation of the vessel and its components to a minimum.

The partial pressures of the deuterium and helium in the sub-divertor volume are measured using a Penning gauge, which is a well-established technique. In this paper, a new approach to the measurement is described, which is particularly useful for plasmas with high and varying concentrations of helium.

2. STANDARD METHOD

The use of a Penning gauge as excitation source for the measurement by optical spectroscopy of the partial pressures of tokamak exhaust gases is well known[3]. A detailed description of the JET system is to be found elsewhere[4]. The Penning gauge is mounted about 2.8m below the divertor, by means of a vacuum tube of suitable length. Light from the Penning discharge is collected by a lens and relayed using an optical fibre to a place outside the biological shield. At this location, the light intensity is measured at two transition wavelengths, those of D_α and HeI at 656.1 and 587.6 nm, respectively, using two photomultipliers, each equipped with an interference filter of the appropriate wavelength. In the range of 10^{-5} to 5.10^{-3} mbar, approximately, the intensity in each channel is proportional to partial pressure.

In figure 1(a) the triangular points show the variation of the D_α signal with pressure, for pure D_2. (The fitted curve is discussed in section 3.) The response of the HeI channel to helium is similar, but more linear with pressure. However, a complication is that the He signal is polluted by molecular emission from the D_2. This is taken into account through system calibration. Figure 1(b) shows the variation of the HeI signal with partial pressure for three different helium concentrations, having subtracted any cross talk.

The relationship between the D_2 and He partial pressures, p, and the intensities, I, in the two channels is given by:

$$p(D_2) = A_{11}.I(D_2), \quad (1)$$

$$p(He) = A_{21}.I(D_2) + A_{22}.I(He). \quad (2)$$

In the above equations, the coefficients A_{11} and A_{22} relate D_2 and He signal intensities to the corresponding partial pressures, whilst coefficient A_{21} represents the D_2 cross talk in the He channel. During calibration, without plasma, using pure D_2 the intensity in both channels is recorded versus pressure, giving the response to this gas and the cross talk. The process is repeated with a known concentration of He (typically ~ 10%), to yield the system response to that gas. From these data, by taking ratios of intensities versus pressure, as described in detail by Finken et al.[3], the coefficients A_{11} to A_{22} are derived. These are subsequently used to analyse signals obtained with plasma.

In plasmas where the concentration of He varies between 0 - 15% the method works well, although at low pressures the time traces of the calculated results may show large fluctuations. These arise from the method used to calculate the coefficients, which will be poorly defined when taking the ratio of two small signal intensities with significant noise content. However, in plasmas where the He concentration changes markedly during a discharge, and rises to many tens of percent, for all pressures the results become inaccurate whenever the concentration becomes significantly different from that used for calibration. This arises because the sensitivity of each channel varies with the gas concentration, due to changes in the characteristics of the Penning discharge with mixture. Figure 1(b) illustrates this dependence for helium; it can be seen that the response at a given pressure increases with increasing concentration.

3. NEW METHOD

At JET, a new approach to calibration and analysis overcomes both problems described in the previous section. System calibration is performed for a range of concentrations of He in D_2 from 0 to 100%. For a finite concentration of either gas, the variation of intensity, I, with partial pressure, p, is well fitted by:

$$I = A[1-\exp(-p/p_0)], \quad (3)$$

where the value of A and p_0 depend on the gas species and its concentration, C. A curve of the form described by Eq. (3) is fitted to the data points in figure 1(a).

Equation (3) tends smoothly to zero as p decreases, avoiding the possibility of spurious fluctuations at low pressure. In turn, A and p_0 vary monotonically with gas concentration, C. The triangular points in figures 2(a) and 2(b) show the variation of A with concentration, for D_2 and He respectively. The data are well fitted by simple exponential functions of C, as shown in the figures. For deuterium, the variation of both A and p_0 with C is well described by an equation analogous to Eq. (3). In the case of helium, the variation of the two parameters with C follows an offset exponential growth.

To process signals obtained with plasma, the following analysis is performed on the data at each time point. Starting with values of C of unity, initial values of A and p_0 are calculated using the relationships established from calibration. The pressures, p, are then adjusted iteratively until the intensities, I, calculated from Eq. (3), match those observed. These pressures yield new values of C, enabling better values of A and p_0 to be derived. The process is repeated until convergence to the required precision is obtained.

4. RESULTS

The new method has been verified by its application to an analysis of calibration data. Figure 3(a) shows three traces of the temporal evolution of total pressure for a He concentration of 50%. Trace 1 is the absolute pressure measured using a capacitance manometer. The pressure derived using the new method is shown in trace 2, whilst trace 3 is that derived using the standard method, with coefficients from a calibration with pure helium. Clearly, trace 2 is in good agreement with the absolute pressure measurement, whilst trace 3 exhibits a discrepancy which rises to over 30%.

Figure 3(b) illustrates the results obtained by applying the two methods to the analysis of data obtained in a discharge where the He concentration rose to ~95%. The standard method made use of coefficients from a calibration with a He concentration of 50%. The calculated helium pressure is then too high by almost a factor of two.

5. CONCLUSIONS

A new method has been described for using a Penning gauge to measure the partial pressure of helium in a tokamak exhaust. Its advantage is that it can reliably measure partial pressures for changing and high concentrations of He. A disadvantage is that a number of calibrations are required over a range of He concentrations from 0 – 100%.

6. REFERENCES

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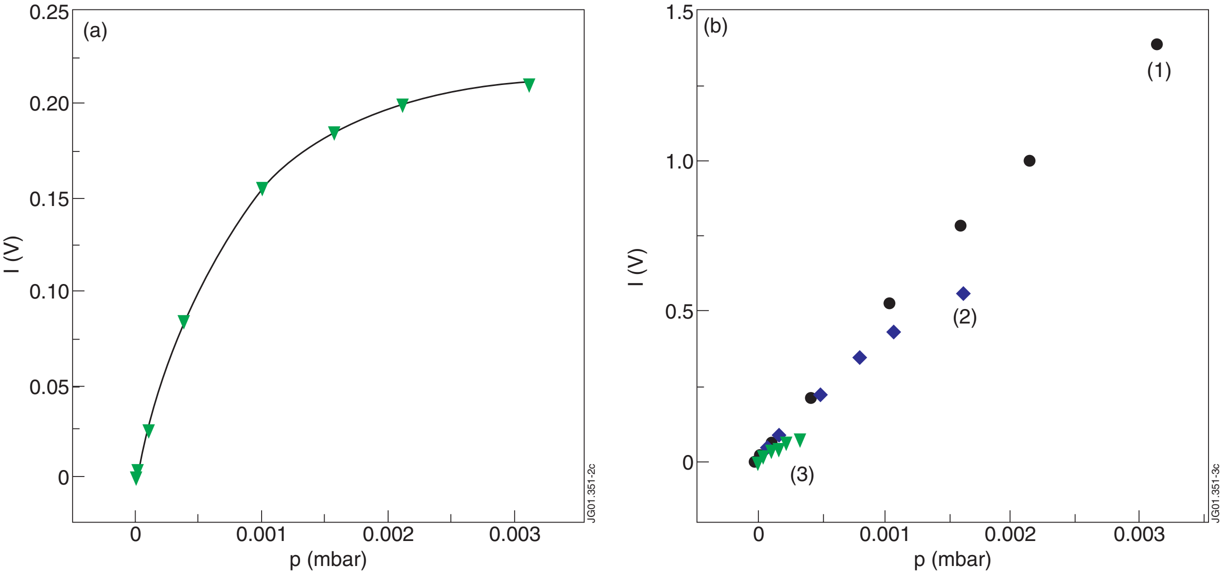


Fig.1: Variation of signal in each channel with partial pressure. a) D_α signal for pure deuterium. b) HeI signal at three concentrations of helium in deuterium: 1) 100%, 2) 50% and 3) 10%.

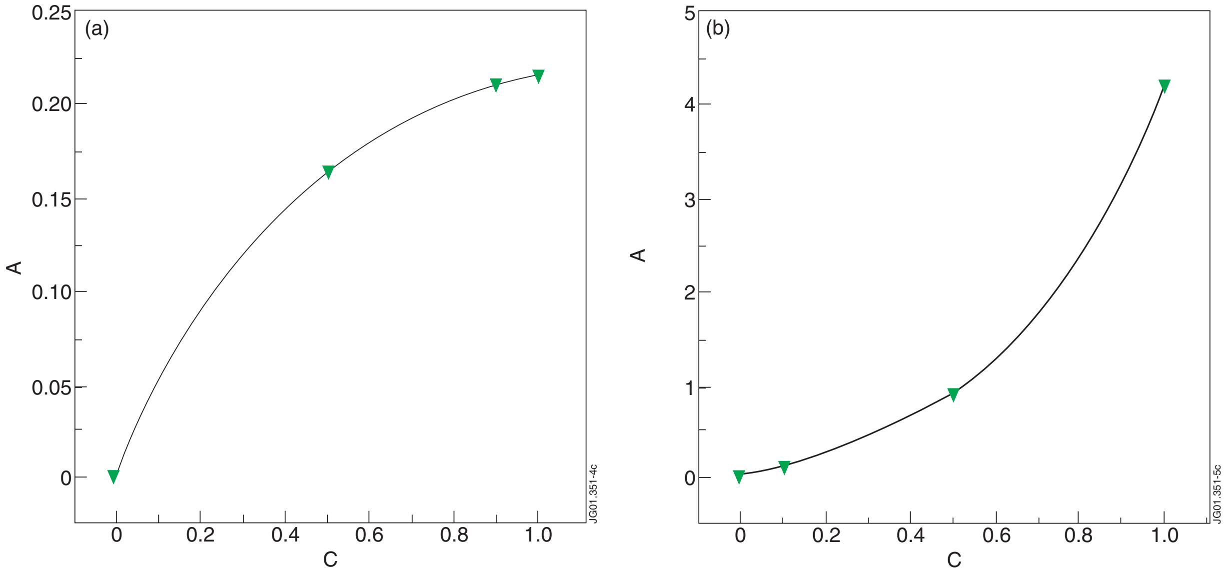
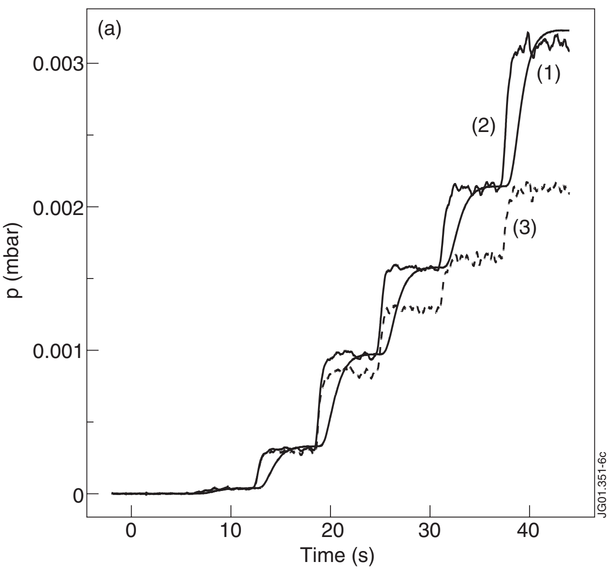


Fig.2: Variation of parameter A with concentration C of relevant gas. a) Deuterium. b) Helium.



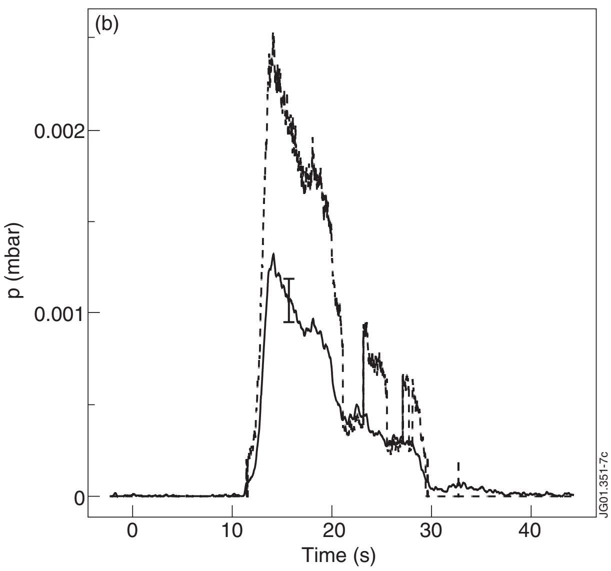


Fig.3: Comparison of results derived using the two analysis methods. a) Total pressure in a 50:50 D_2 / He mixture used for calibration: 1) capacitance manometer, 2) new method and 3) standard method. b) Helium pressure during a discharge: solid line - new method (error bar +/- 12%), dashed line - standard method.