Analysis of Reflectometer Density Profile Measurements in JET

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INTRODUCTION

Reflectometry is a useful tool to diagnose the electron density in fusion plasmas. Various methods in reflectometry are used to obtain information on the electron density profile [1, and refs. therein]. However, routine measurements of the density profile on a Tokamak plasma have not been reported. All measurements of the density profile rely on the phase change of the probing microwave beam, along the propagation path, induced by sweeping the source frequency. In general, difficulties in the measurement and analysis of reflectometer data are caused by the effects of plasma fluctuations. In this paper a technique for measuring the density profile is given which combines the swept frequency and fixed frequency measurements. The results of the analysis are described and discussed, followed by the conclusions of this paper.

THE MULTICHANNEL REFLECTOMETER AT JET

With the twelve-channel reflectometer, that has been developed and constructed for JET [2,3], the plasma is probed along the midplane of the torus. The frequencies lie in the range 18 to 80 GHz, with radiation polarised in the O-mode, corresponding to densities in the plasma between $4x10^{18}$ m^{-3} and $8x10^{19}$ m^{-3}. The density profile can be measured by sweeping the sources over narrow frequency ranges (typically 100 MHz), while local variations in the electron density are monitored using the fixed frequency mode. The reflectometer has two detection systems. Coherent detectors, which measure both the wave amplitude and phase with a minimum sample time of 2 μs., are used to study density fluctuations in the plasma [4]. Fringe counters are used to measure phase with an accuracy of 1/128 of a fringe with a minimum sample time of 10 μs.

MEASUREMENT TECHNIQUE

The measurement of electron density profiles in JET, using reflectometry, encountered major difficulties due to the effects of the density fluctuations in the plasma. The effects of the density fluctuations is reduced by positioning of the launch and receive antennas close to the plasma, by strong filtering of the input signals to the fringe counters (bandpass of 3 kHz) and by maximising the dynamic range of the system, using high gain amplifiers.

A special technique for the frequency sweeps has been developed in which each sweep of the source frequency (up or down) is followed by a fixed frequency period of comparable length in time which in effect generates upper and lower baselines. This operation mode is called trapeze sweep (Fig. 1), and can give continuous information in time on the electron density profile.

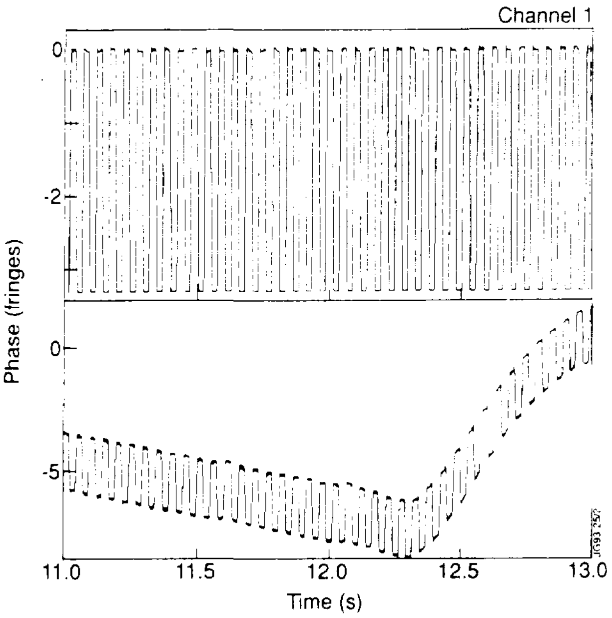

Figure 1 Two examples of the trapeze sweep mode of operation. In the upper trace the measurement of a fringe counter is given for a calibration measurement from the inner wall. The lower trace shows the measurements of channel 1 during pulse 24116

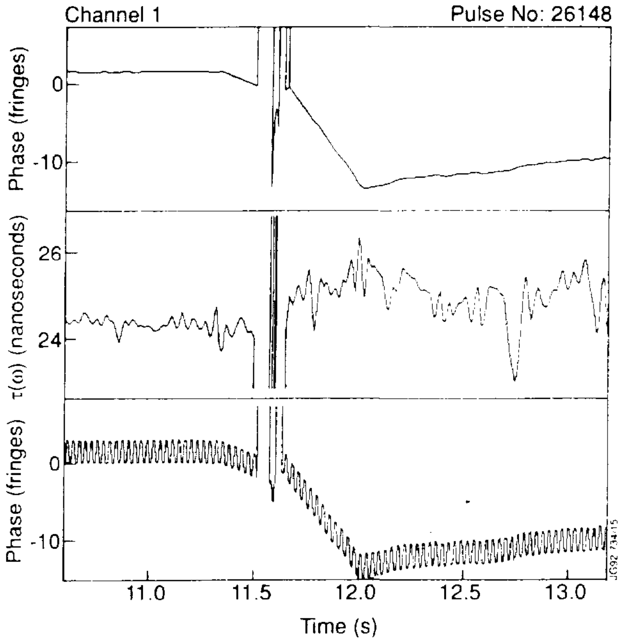

Figure 2 The propagation delay τ can be calculated continuously from the data by dividing the phase difference between the two baselines by the frequency sweep (middle trace). The top trace shows the evolution of the phase at the source frequency.

ANALYSIS METHOD

All measurements of the phase variations in the trapeze sweep mode of operations are carried out by the fringe counters. First, single fringe jumps and phase run-away periods as a result of the plasma fluctuations are eliminated or identified. Second, in the trapeze sweep mode of operation the evolution the density profile is monitored alternately at the source frequency and at the source frequency plus the magnitude of the frequency sweep. The propagation delay τ can be calculated continuously from the phase difference between the two fixed frequency baselines (Fig. 2). The resulting uncertainty on these τ values is still substantial (≈ 1 nanosecond) . However, from the measured phase variation at the fixed source frequency (top trace Fig. 2) the evolution of τ can be determined. In this case the absolute value is determined by all the frequency sweeps during the total time interval of the analysis. This technique calculates the density profile and measured changes to the density profile consistently.

A computational sequence can be set up in which the τ values are Abel inverted to generate a density profile. This is followed by a new calculation of the τ values using the phase variation at fixed frequency and the refractive index calculated from the estimated density profile. This sequence is repeated until a stable and consistent solution is obtained. For the

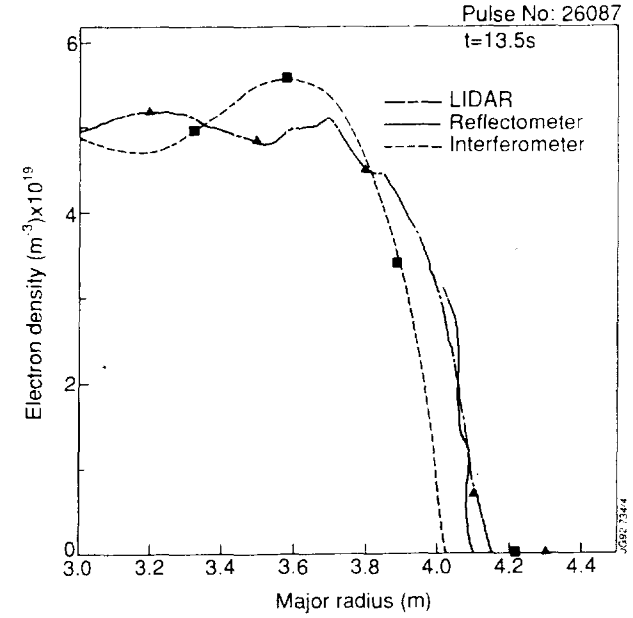

Figure 4 The density profile of the reflectometer is compared to the measurement of the electron density by means of LIDAR Thomson scattering and the multichannel interferometer at JET.

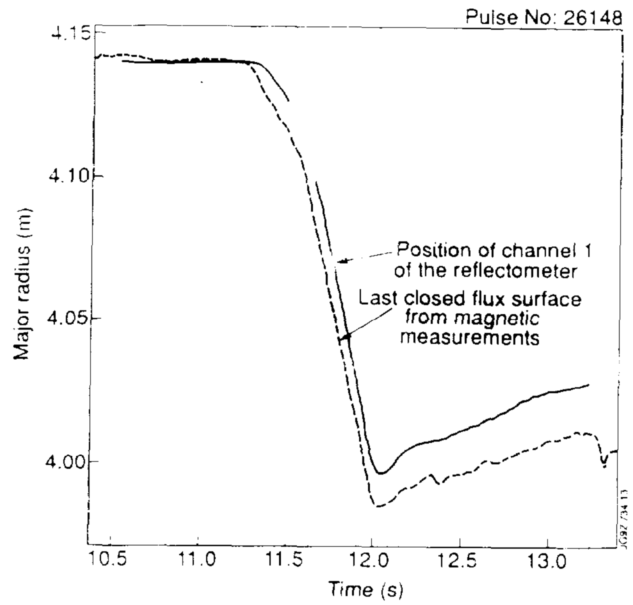

Figure 5 The evolution of the position of the plasma edge measured by reflectometry is compared with the calculation of the position of the last magnetic flux surface.

CONCLUSIONS

A new measurement technique is described which gives continuous information on the electron density profile in time. The combination of fixed frequency and swept frequency reflectometry measurements results in an accurate and reliable measurement of the electron density profile in JET. The analysis of the data can be carried out routinely for each discharge at JET providing the plasma edge is not too turbulent. The absolute position of the density profile is measured with an accuracy of 3 cm, and the evolution of the profile with an uncertainty of less than 1 millimetre. The profiles compare well with other measurements of the electron density at JET.

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