MEASUREMENTS OF 'SNAKES' FOLLOWING MULTIPLE PELLET FUELLING OF JET

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INTRODUCTION

The extremely long lived density perturbation, or snake, first seen by the soft X-ray cameras following single pellet injection into JET[1], has now been observed following multiple pellet fuelling of JET discharges[2]. The snake is caused by a local density perturbation rotating at a rational q-surface, normally the q=1 surface. The snake can persist for longer than 2 seconds, suggesting that . magnetic island is formed at the rational q-surface, with ablated pellet particles being deposited inside this island. The long snake lifetime implies a change to a new non-axisymmetric equilibrium[1].

New diagnostics have contributed important new results on the study of snakes. Particularly an array of toroidal soft X-ray cameras and the LIDAR Thomson Scattering system[3], which makes simultaneous measurements of the electron temperature and density profiles possible. These will be presented in this paper, with particular emphasis on the creation of snakes and the subsequent snake profiles.

CERTAIN NECESSARY CONDITIONS FOR THE CREATION OF SNAKES

The soft X-ray signals for two time periods of 1 millisecond each recorded during the injection of successive D_2 pellets, the second of which created a snake, are shown in Fig.1. The upper signals are from the vertically mounted camera which views the incoming pellet trajectory. The bottom signal is that of a central detector in the horizontally mounted camera which views the injected pellet from behind and gives a measure of the pellet ablation rate. The two soft X-ray cameras[4] are located at the same toroidal position as the multiple D_2 pellet injector. Both pellet trajectories are clearly visible in Fig.1. In Fig.1a the maximum rate of pellet ablation is seen to occur around 60cms, which is outside the sawtooth inversion radius of 45cms, as determined from a tomographic analysis of the soft X-ray data[5]. Throughout this paper the sawtooth inversion radius is taken as being equivalent to the q=1 position. For the second pellet, shown in Fig.1b, the sawtooth inversion radius is determined to be at 42cms. This pellet is observed to penetrate well beyond this radius, with considerable pellet ablation occurring in the region of the q=1 surface. Around such a rational surface, the particles would not be expected to spread rapidly. A local drop in temperature could therefore occur, as only the electrons inside a narrow flux tube which intersects the pellet trajectory would interact with the pellet.

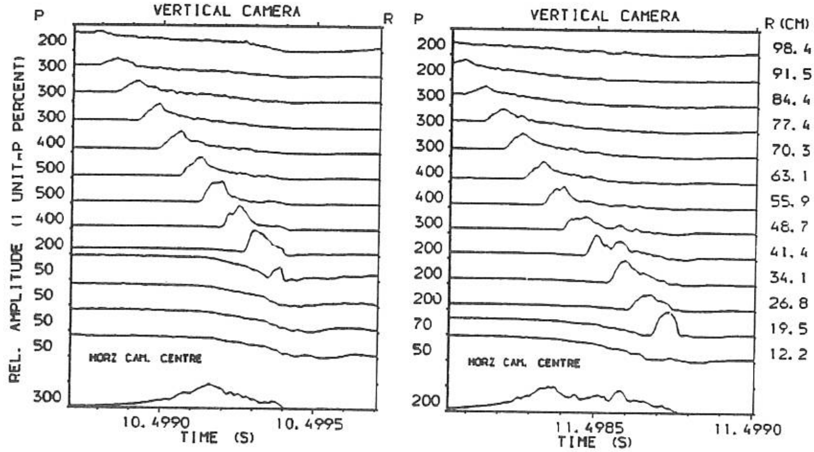

FIG.1: X-ray signals during the injection of two successive D_2 pellets, the second of which created a snake.

In Fig.2, LIDAR profiles of the electron temperature and density across the horizontal mid-plane of JET are shown, 19 milliseconds after the injection of a pellet which created a snake. At the sawtooth inversion radius, a clear local density enhancement and temperature depression are seen and it is this density perturbation which is labelled a snake. Local cooling is therefore observed at the q=1 surface, which can lead to a helical current perturbation and the formation of a magnetic island.

Certain necessary, although perhaps not sufficient, conditions for the creation of a snake are, therefore, firstly that a q=1 surface must exist within the plasma, secondly that the pellet must reach this q=1 surface and thirdly that sufficient pellet particles are ablated in the region of the q=1 surface so as to lead to the formation of a magnetic island.

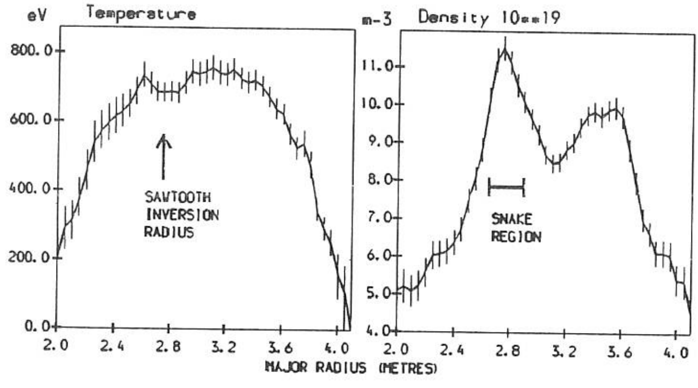

FIG.2:

Radial electron temperature and density profiles, 19 milliseconds after the injection of a pellet which created a snake.

SNAKE PROFILES AND THE SNAKE LIFETIME

From the soft X-ray cameras and toroidal detectors it is found that the snake has an m=1, n=1 structure, with typical dimensions (FWHM) of 25cm poloidally and 17cm radially, which is in good agreement with the radial dimension of the perturbation determined from the LIDAR profiles of Fig.2. From this knowledge of the mode structure, it can be determined from the soft X-ray data that the peak of the snake lies above the horizontal mid-plane at the toroidal location where the LIDAR profiles of Fig.2 are measured. The maximum density and temperature perturbation at this time is, therefore, considerably larger. Indeed, for this particular snake, the ECE grating polychromator experienced a periodic 2nd harmonic X-mode cutoff at the snake radius. From the maximum frequency at which the cutoff was observed, the density of the perturbation was determined to be 1.5×10^{20} m^{-3} ($\pm$ 10%) compared to the density measured by the LIDAR of 1.15×10^{20} m^{-3}. Further, this is not seen to change over a period of 350ms, at which time the plasma current was ramped down, implying an effective confinement time for the snake of the order of several seconds.

In Fig.3, the radial soft X-ray profile measured by the vertically mounted camera is shown. A pellet is injected at 8.5 seconds which creates a snake. This is seen to rotate for a period of 900ms before slowing down and stopping. This snake is observed to survive through many sawteeth, as is the case with all other snakes[1]. At 10 seconds, when LIDAR profiles were measured, the centre of the snake is determined from tomographic analysis of the soft X-ray data to be just above the horizontal mid-plane at the LIDAR port. These LIDAR electron density and temperature profiles are shown in Fig.4. The snake is clearly seen in the density profile, centred at 3.35m. The temperature profile over the corresponding region of this snake shows the temperature falling from about 1700 eV at 3.15m to 1450 eV at 3.5m. This does not show any equalization on either side of the snake, as might be expected if the density is confined within a magnetic island.

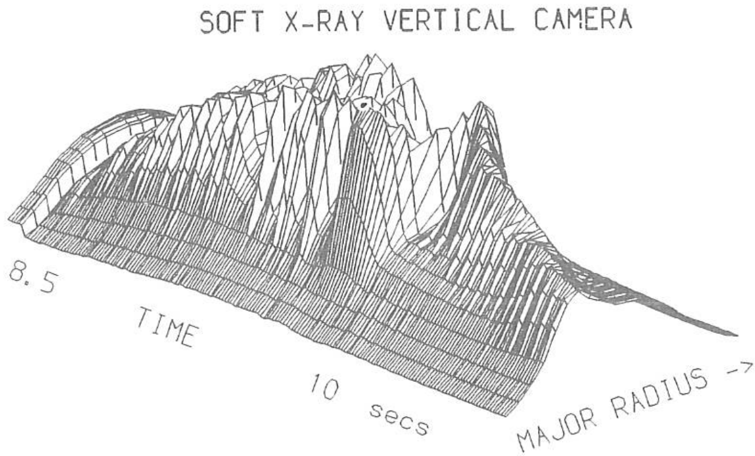

FIG.3: Soft X-ray flux around the time of pellet injection showing the 'snake' oscillation.

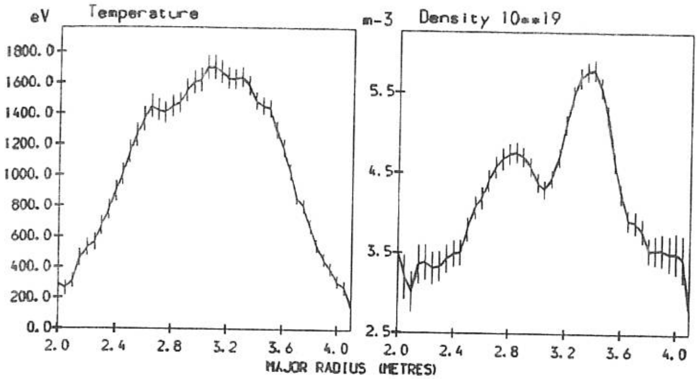

FIG.4:

Radial electron temperature and density profiles 1.5 seconds after the creation of a snake.

These LIDAR profiles are, however, taken at a time when the snake is 'locked' in one poloidal location. As the snake is an island deep within the plasma, if it is to 'lock', it must couple to a mode further out in the plasma which can interact with the vessel wall[6]. The magnetic signals show the presence of a large locked mode at this time. It might not, therefore, be expected that the temperature would be equalized at the extremes of the island at this time, as the snake has coupled to another mode. From Fig.3 it can be seen that, subsequent to these LIDAR profiles, the density perturbation decays away on a timescale of the order of 1 second. In other cases where the snake has been observed to couple to a 'locked' mode, then the density is seen to decay on a similar timescale. The application of on-axis ion cyclotron radio frequency heating (ICRH) is also observed to lead to the decay of the snake. The density is seen to decay on a timescale of the order of 100 milliseconds about 200 milliseconds after the ICRH is applied to the plasma.

SUMMARY

In conclusion, snakes have been observed during multiple pellet fuelling of JET. LIDAR Thomson scattering profiles of electron temperature and density provide clear measurements of the conditions necessary for the formation of a magnetic island at a rational q-surface in which a fraction of the ablated pellet particles can be trapped. ECE measurements in which a persistent periodic cutoff is seen at the snake radius implies a very long effective confinement time for the snake. The presence of 'locked' modes in the plasma, to which the snake can couple, or the application of on-axis ICRH leads to a gradual decay of the snake.

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