

Characteristics of a new Class of Transport related MHD Modes in JET H-mode Plasmas

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A new type of MHD mode, provisionally termed the Wash Board (WB) mode[1], has been observed during H-mode plasmas in JET. It occurs in all types of H-mode discharges, but is not seen during L-mode even at high values of β . The WB mode appears to be linked with saturation in the plasma confinement and central plasma temperatures (figures 1 and 2). These modes have high m and n numbers and are localised in the outer part of the plasma, typically from the $q=2$ surface to the plasma edge. They rotate with the electron diamagnetic frequency and have a strong ballooning character. They are regarded as a possible candidate to play a role in the confinement degradation of H-mode plasmas.

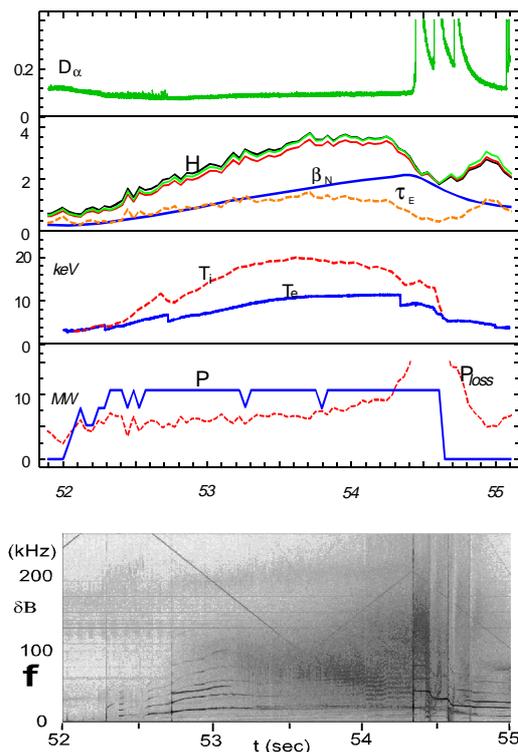


Fig. 1. Time traces of various parameters in the Hot-Ion H-mode phase of Tritium discharge #42840, with $I_p = 3.9$ MA, $B_T = 3.4$ T. From top to bottom: (i) the D_α trace, (ii) the nearly identical Goldston, JETDIII-D and ITER89-P H-multipliers together with the plasma normalised pressure β_N and the energy confinement time τ_E , (iii) the central ion T_i and electron T_e temperatures, (iv) the NBI input power P and the loss power P_{loss} . The time evolution of the spectrum of the fluctuating signal from a magnetic pick-up coil at the low field side 37° up from the mid-plane is shown at the bottom. The amplitude scales are logarithmic. The $n=1$ mode and its harmonics present in the early stages of the heating phase die out after 53 s. There is also a frequency sweep visible between 100 and 300 kHz by the TAE excitation coils. Around 53 s the pattern of modes, which we refer to as "washboard" modes starts to grow between 0 and 150 kHz. A sawtooth occurs at 54.34 followed by post-cursor modes, Outer Modes and ELM's. This lead to the termination of the Hot-Ion H-mode phase

Apart from other MHD activity [2], during the evolution of the H-mode phase in JET, there is a diffuse background in the spectra of the signals from magnetic pick-up coils, which is observed to increase as β increases.

This background can contain two types of modes: one which rotates in the electron diamagnetic direction with mode frequencies between 10 kHz and ~ 100 kHz and a second type, if β is high enough, which is rotating in the opposite direction at higher frequencies (100 kHz to 200 kHz, but below the TAE frequency [3]). The "electron diamagnetic" modes start shortly after the L-H transition at $\beta_N \sim 1$.

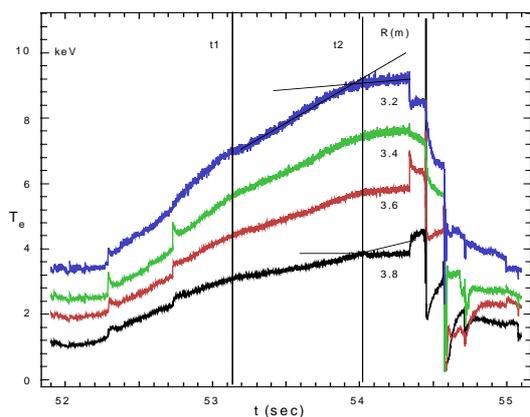


Fig.2 The electron temperature at various radial positions for discharge #42840. The plasma centre is at $R = 3.05$ m. The change in the rate of rise at time t_2 due to the change in WB mode activity is clearly visible on all traces (2.32 and 1.15 keV/s at $R=3.2$ and 3.8 m respectively). A smaller but similar effect is apparent at t_1 when there is also a notable increase in WB mode activity (fig.1).

There is a good correlation between increasing plasma pressure and the growth of both the spectral extent and amplitude of the WB modes. Changes in the electron temperature profile (fig.2) also correlate well with changes in the amplitude of these modes. They are therefore regarded as a possible candidate to explain part of the confinement/power degradation of the empirically established H-mode scaling laws. That these modes are not observed in L-modes is surprising because the power degradation of energy confinement is qualitatively similar to the H-mode. The difference might lie in the H-mode plasmas having large pressure gradients near the edge, enabling magnetic fluctuations to be detected. Indeed at the H to L transition the frequency of the WB modes falls by 2 orders of magnitude, making it practically impossible to detect them and analyse if they still exist.

DISPLACEMENTS

WB modes are visible not only as magnetic fluctuations but also as fluctuations of the electron density and, weakly, of the electron temperature. Therefore the radial position of the WB modes can be found by determining the radial location of the density and temperature fluctuations. The WB modes are strongly modulated by ELMs and also by Outer Modes (Outer Modes are external kink modes localised near the plasma edge [2]). This suggests that their origin must lie close to the plasma edge. However, in Optimised Shear discharges, which have a sufficiently peaked density profile that the O-mode reflectometer can measure to almost the plasma centre, it is found that the density fluctuations associated with the WB modes extend from the edge into the internal transport barrier and occasionally beyond (fig.3).

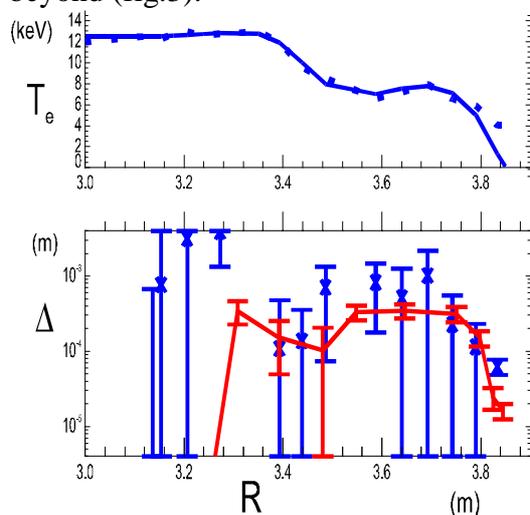


Fig.3. Optimised Shear H-mode discharge 41629 at $t=46.859-46.875$ s. Displacements are deduced from T_e and n_e fluctuations due to the WB mode at 43 kHz using the measured temperature profile and the density fluctuations. The (m,n) mode structure is $(-14 \pm 2, -7 \pm 1)$. The top figure shows a functional fit (solid line) to the ECE T_e profile (dotted line). The lower part of the figure shows the displacements deduced from density fluctuations (error bars connected by solid line) and temperature fluctuations (error bars marked with X). The error bars are obtained from the least-square fit of an offset Gaussian to the MHD activity spectrum around 43 kHz.

CORRELATIONS

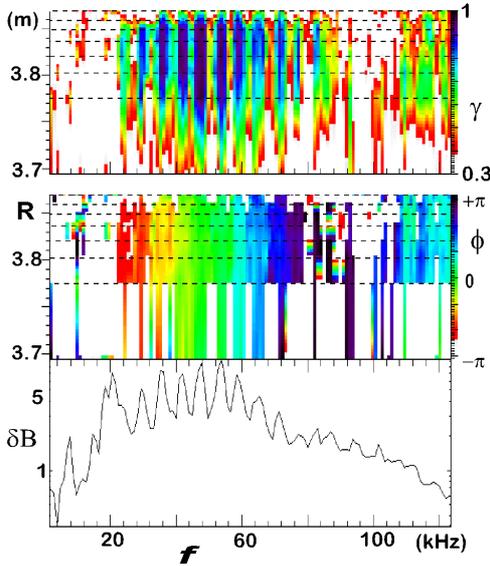


Fig.4. Coherence, γ and phase spectra, Φ , as functions of major radius R for the discharge #42840 at $t = 54.049$ - 54.065 s. The colour scale for γ and Φ is shown at the right of each plot. The signal from a magnetic pick-up coil in the same octant is used as the reference. Its power spectrum δB is shown in the lower part of the figure. In the upper plots, the dotted lines mark the positions of the reflectometer channels. The coherence and phase values are interpolated between these radii.

It can be seen that the phase of the fluctuations, with respect to a magnetic pick-up coil in the same octant, varies from $-\pi$ to π over the frequency range of 24 kHz to 76 kHz. This phase variation occurs because of the spatial separation of the magnetic pick-up coil and the location of the reflectometer. This shows that the phase of the density fluctuations is in anti-phase with the poloidal magnetic field fluctuations. Also it can readily be seen that there is no phase change over radius for the WB modes.

TRANSPORT

The discharges with high concentrations of Tritium and moderate NBI heating which were produced during the JET alpha heating experiments [10] are characterised by periods with little or no MHD activity other than WB modes. Additionally, in two of these discharges (#42847 and #42840) there is a sharp transition in the level of WB mode activity (as was shown in fig.1). By studying the evolution of the electron temperature during this sharp transition we can investigate the influence of this MHD activity on the plasma confinement. In discharge #42840 the transition occurs at $t=54.05$ s (fig.1). In fig. 2, the changes in the electron temperature at various plasma positions during the increase (at $t = t_2$) in WB mode activity are shown. Before the transition the temperature at $R=3.6$ m is increasing linearly at a rate of 1.7 keV/s and after the transition the rate of rise falls to 0.3 keV/s. Also note, that the start of the WB modes coincides with another change in the rate of rise of the electron temperature, at $t=t_1$.

It is difficult to prove beyond doubt that WB modes alone are responsible for confinement degradation. However, another result also points to their importance: there is a good correlation between an increase in the electron plasma heat conductivity and an increase in WB mode activity. Figure 5 shows the $\chi_e(R,t)$ calculated by TRANSP for the same discharge as fig.1. At 53 s the χ_e is low nearly everywhere, but it then increases gradually, starting from the edge. At the same time, 53 to 54.3 s (see fig. 1) the WB modes start to grow in amplitude and in number. From 53.7 s onwards changes in WB modes are reflected in changes in χ_e ,

particularly around 54.0 s. The change around 54 s in the WB mode activity is associated with changes of the χ_e in the region between 3.6 - 3.8 m from 0.06 to ~ 0.2 m²/s.

However after $t=54.15$ s there is a further increase of the electron heat conductivity as can be seen in fig.5. This latter is not associated with an increase in the WB mode activity. However there is a significant increase in the amplitude of high frequency density fluctuations between 100 and 250 kHz.

We conclude that WB modes are one contributing factor to the heat losses of the plasma electrons, but are not the only mechanism responsible for these losses in these "MHD quiescent" plasmas. And as can be seen from fig.5, the other MHD activity (Outer modes and neo-classical type of modes) after the sawtooth at $t = 54.34$ s, leads to much higher electron heat losses.

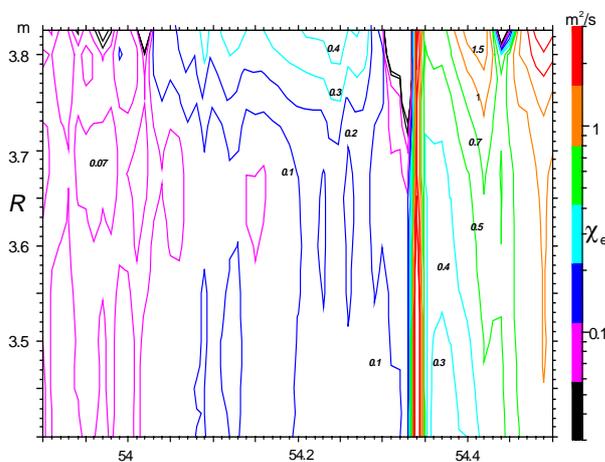


Fig.5. The electron heat conductivity $\chi_e(t,R)$ in the Hot-Ion H-mode #42840. The change in electron heat conductivity at 54 s is associated with the change in the WB mode spectra. This is a clear indication of the effect of the WB modes on plasma transport. The changes after 54.34 s are related to other MHD phenomena: Sawtooth, Neo-classical type of modes, Outer Modes and ELMs.

SUMMARY

The WB modes are clearly linked with the H-mode phase of JET discharges. They grow in amplitude and expand in frequency with increasing β . They have a strong ballooning character and do not appear to be of a tearing type. Typical radial displacements as deduced from density and temperature fluctuations in the ELM-free hot-ion H-modes are of the order of few millimetres. The mode amplitude varies strongly in time with a time constant of less than 250 μ s. It appears most likely that the WB modes originate in the plasma edge but extend further inwards, occasionally to the plasma centre. There are many more WB modes in the outer part of the plasma than in the core. The WB modes appear to be linked to the saturation in H-mode plasma confinement and their properties are consistent with measured electron transport.

The precise nature of the WB modes still needs further theoretical investigations.

[1] P.Smeulders et al, accepted for publication by Plasma Physics and Controlled Fusion, 1999, also JET report JET-P(98)83

[2] M.Nave, et al, Nuclear Fusion 37(1997)809

[3] S.Sharapov, A.Mikhailovskii, et al, 'Interpretation of Electromagnetic Modes in the Sub TAE Frequency Range in JET', to be published (1998).