CHARACTERISTICS OF HIGH FREQUENCY TURBULENCE DURING EDGE LOCALIZED MODES IN THE HL-2A TOKAMAK

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Edge localized modes (ELMs) in tokamak plasmas are edge instabilities that manifest in high confinement mode (H-mode) and temporarily disrupt the edge transport barrier for the brief duration of the mode [1]. It is well established that ELMs are predominantly turbulent phenomena, with turbulence levels significantly higher than those observed in ELM-free H-mode. While much of the research has focused on the onset of ELMs and ELM pre/post-cursors [2, 3], fluctuations occurring during the ELM event itself have received less attention, in part due to the short duration of the ELM.

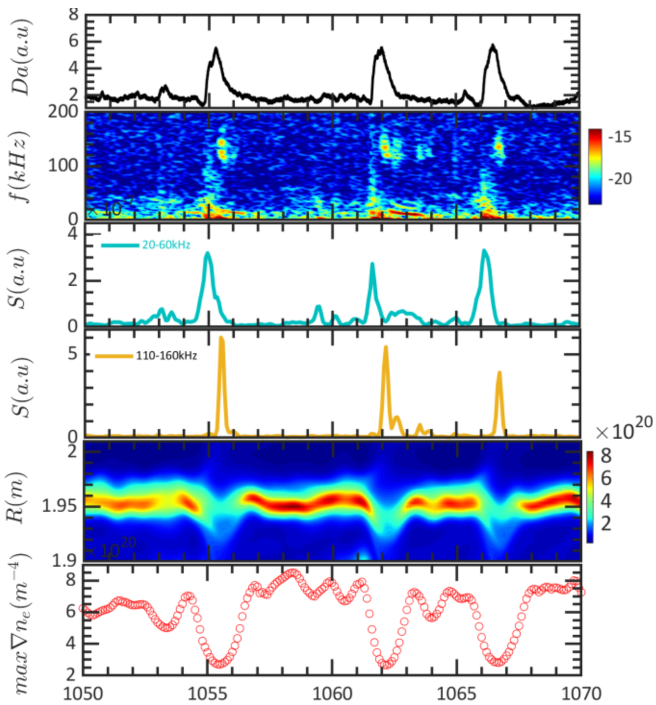

Figure-1. Time evolution of: (a) D_α intensity, (b) spectrogram of turbulence measured by BES at the pedestal region, (c) turbulence intensity integral in f = 20~60 kHz, (d) turbulence intensity integral in f = 110~160 kHz, (e) electron density gradient profiles, (f) maximum of density gradient.

In this work, the characteristics of ion-scale turbulence during the ELMs are investigated. The diagnostic employed in this study is the beam emission spectroscopy (BES) system, which measures the density fluctuations at the edge of the tokamak. The BES system on HL-2A consists of 32 spatial channels, and is capable of measuring the density fluctuations in the region of r/a = 0.8−1.1. Figure 1 shows the time evolution of turbulence and electron density gradient in the pedestal region during H-mode phase. Figure 1(a) shows the D_α intensity, clearly indicating the occurrence of ELMs in the H-mode. Figure 1(b) shows the spectrogram of turbulence measured by BES system at the edge pedestal region of H-mode. As the ELM occurs, the turbulence intensity increases significantly. It can be observed from Figure 1(b) that there is a time delay between the low frequency (f = 20~60 kHz) turbulence and the high frequency (f = 110~160 kHz) turbulence when ELM occurs. This can be clearly demonstrated in the integral turbulence intensity at different frequency range, as shown in Figure 1(c) and 1(d). For the low-frequency (f = 20~60 kHz) turbulence, the turbulence intensity increases immediately with ELM burst. In contrast, the turbulence intensity in high-frequency (f = 110~160 kHz) also increases with the during the ELM event but with a noticeable time delay relative to the ELM or the low-frequency turbulence. Figure 1(e) and 1(f) shows the evolution of electron density gradient during the H-mode. It is observed that the edge electron density decreases due to the ELM burst and subsequently recovers during the inter-ELM phase. Correspondingly, turbulence intensity is suppressed, and plasma confinement is restored to the H-mode state.

The characteristics of the high-frequency mode during edge localized modes (ELMs) are analyzed using the Beam Emission Spectroscopy (BES) system. This high-frequency mode propagates in the ion diamagnetic drift direction, with a poloidal wavenumber of $k_\theta \sim 0.5\, cm^{-1}$. It is also observed in the magnetic fluctuation spectrum, suggesting that it exhibits electromagnetic properties. A bi-spectrum analysis reveals a nonlinear interaction between this high-frequency mode and broadband turbulence, indicating that the high-frequency mode plays a role in turbulent transport in the edge region. Further investigation shows that the delay time between the onset of the high-frequency turbulence and the ELM event is correlated with the size of the ELM. Figure 2 presents the time delay ($\Delta\tau$) between the high-frequency mode and the low-frequency mode, plotted against the energy loss associated with the ELM ($\Delta W/W$), which serves as a proxy for ELM size. Notably, as the delay time decreases, the ELM size increases. Additionally, the recovery time of the plasma pedestal following an ELM crash is shorter for larger ELMs, implying that the shorter delay times is linked to faster recovery. These findings suggest that the high-frequency mode may influence the pedestal dynamics through turbulent transport processes. Specifically, the high-frequency turbulence may impact the rate of pedestal recovery after an ELM. The observed correlation between delay time and ELM size further supports the hypothesis that turbulent interactions at the edge region play a critical role in the response of the plasma to ELMs.

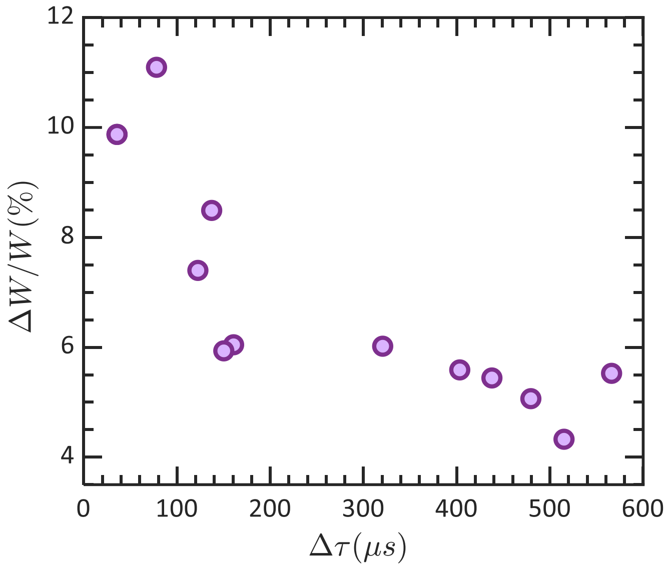

Figure-2. Time delay of high frequency turbulence and the low-frequency turbulence against the energy loss caused by ELM

References

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