EUROFUSION CP(15)05/01

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Electromagnetic Turbulence Measurements During the L-H Transition in the TJ-II Stellarator

(22nd June 2015 – 26th June 2015)
Lisbon, Portugal

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Electromagnetic turbulence measurements during the L-H transition in the TJ-II stellarator

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I. Introduction

It is well known that sheared flows can suppress turbulence and help to improve plasma confinement. Fluctuating, turbulence-generated zonal flows are a benign non-linear turbulence saturation mechanism, consistently observed in simulations and reported in several experiments. Because of their transport modulation capability zonal flows have been considered natural candidates for triggering the L-H transition. Theoretically, both electrostatic fluctuation-induced Reynolds stress and magnetic fluctuation-induced Maxwell stress can play a role in generating zonal flows [1]. Whereas measurements of Reynolds stress with multi-pin Langmuir probes have been conducted in several devices [2], only a few measurements of Maxwell stress have been reported [3]. In this work we present local measurements of magnetic properties and Maxwell stresses in the proximity of the L-H transition in the TJ-II stellarator.

II. Experimental setup

Experiments were carried out in the TJ-II stellarator, in the pure NBI heated plasmas (toroidal magnetic field $B_T = 1\,T$, plasma major radius $\langle R \rangle = 1.5\,m$, plasma minor radius $\langle a \rangle \leq 0.22\,m, \iota(a)/2\pi \approx 1.6 - 1.9$). The electromagnetic properties were measured using an electromagnetic (EM) probe (also dubbed 'vorticity probe') [4][5] consisting of a Langmuir probe array and three three-axial magnetic coils, which can measure the time derivative of the three components of magnetic field. The three magnetic probes form a right angle in the radial-poloidal plane. They are separated by 3 cm in both radial and poloidal directions. The Langmuir probe array locates in the middle of two magnetic probes in the radial direction. This setup allows for simultaneous measurements of magnetic and electrostatic properties.

III. Radial profiles of magnetic fluctuation and Maxwell stress

Radial profiles of electromagnetic properties were measured by the EM probe on a shot-to-shot basis in TJ-II. Sixteen shots of similar plasma conditions with probe measured at six different radial positions were taken into account for this analysis. Figure 1a shows the radial profile of magnetic fluctuation (rms). Magnetic fluctuation level increases significantly radially inwards. Maxwell stress was estimated by the time average of the product of radial and poloidal components of magnetic field fluctuation $\langle \tilde{B}_r \tilde{B}_\theta \rangle$. As shown in figure 1b, the Maxwell stress as well as its gradient also increase radially inwards reaching values close to $10^5 m^2/s^2$ at the innermost radial position ($\rho = 0.86$), which were the measurements so far available. When comparing with Reynolds stress previously measured in TJ-II with Langmuir probe, both the level and gradient of Maxwell is relatively low [6]. The frequency resolved Maxwell stress, shown in figure 1c, suggests that the main contribution to Maxwell stress comes from the magnetic fluctuation with frequencies below 50 kHz. This agrees with Maxwell stress measurements from the Extrap-T2R RFP [3].

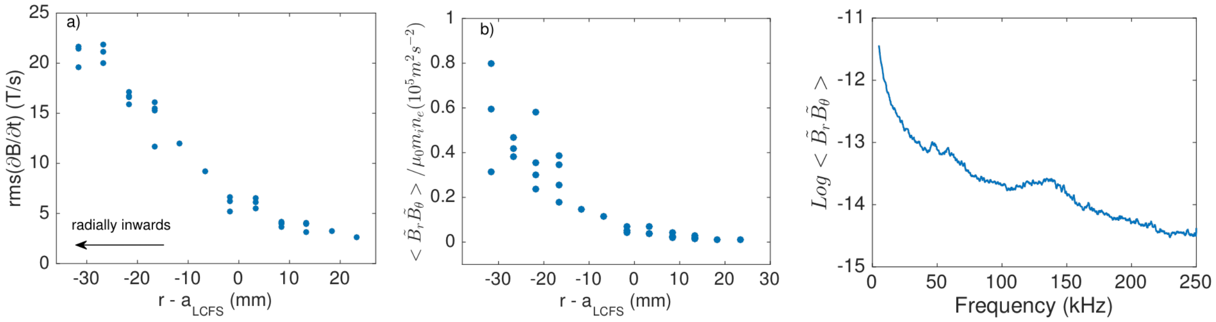

Figure 1. (a) Profile of magnetic fluctuation level, (b) Profile of Maxwell stress, (c) Frequency resolved Maxwell stress.

IV. Electromagnetic dynamics during L-H transition

The time evolution of plasma parameters and edge fluctuations were monitored by the EM probe in the proximity of the L-H transition for the shot #37638, showing a decrease in H_α and the level of electrostatic and magnetic fluctuations. We also notice that in the middle of the H-mode there is a burst (at around $1027\,ms$) which shows up in almost all measured signals, including I_s and parallel current density ($\tilde{j}_\parallel$). This indicates that the burst may be related to some filamentary electromagnetic structure. Further investigation of this ELM-like event is in progress. The reduction of electrostatic and magnetic fluctuation in a wide frequency range can be seen in figure 3.

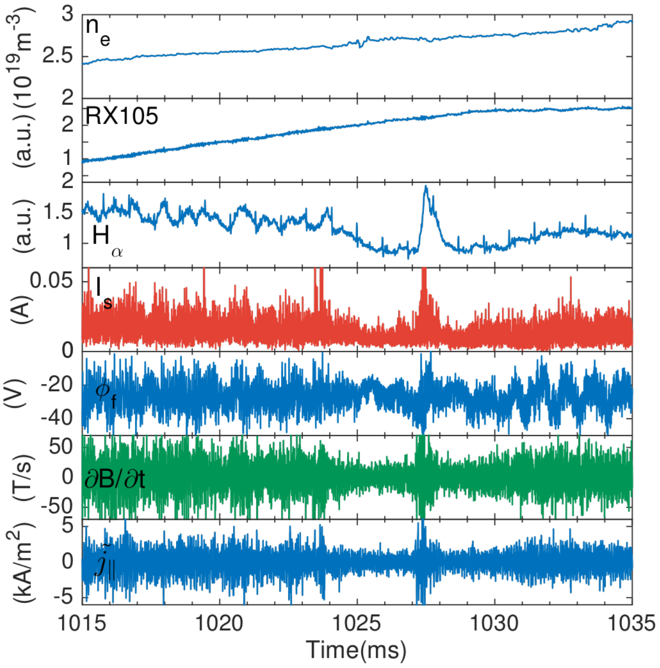

Figure 2. Time evolution of plasma parameters (#37638).

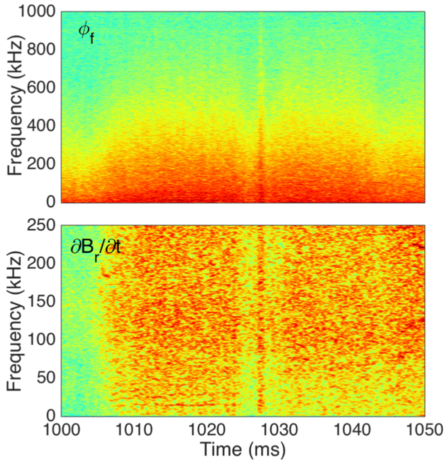

Figure 3. The spectrogram of floating potential and magnetic fluctuation. The sampling rate of floating potential measurement is 2 MHz and magnetic fluctuation measurement is 500 kHz. This results in different frequency scales.

To explore the variation of local electrostatic turbulence structure during L-H transition, we measured the radial correlation length (L_r) and poloidal correlation length (L_θ) with two radial and two poloidal Langmuir probe tips using standard two-point correlation technique: the correlation length L_c was estimated from the broadening of fluctuation power spectrum in the wavenumber axis in the wavenumber-frequency plane. Figure 4 shows the time evolution of the local turbulence structure. L_r decreases as approaching the L-H transition. When L-H transition taking place, L_θ appears to increase.

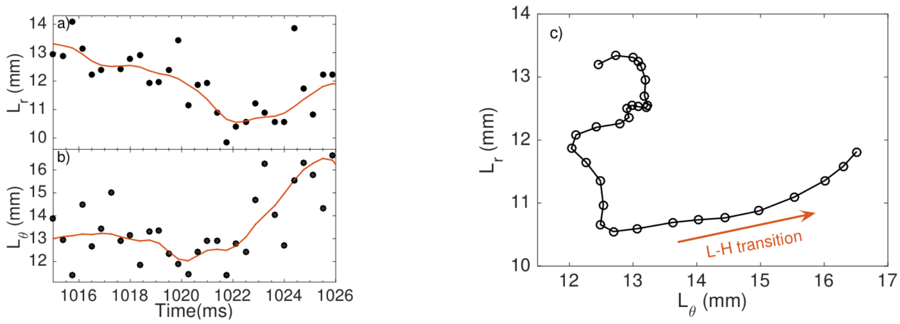

Figure 4. Time evolution of a) radial correlation length (L_r) and b) poloidal correlation length (L_θ), and c) the portrait L_r and L_θ.

Figure 5 shows the time evolution of Maxwell stress measured by three magnetic probes on the EM probe. Maxwell stress measured by probe 1 is significant larger than by probe 2 and 3. This suggests that a gradient in Maxwell stress is formed at the probe location. Considering the distance between two probe is 3 cm, we estimated the gradient of Maxwell stress can reach the order of $10^7 m/s^2$ at around $\rho = 0.9$. This is about one order of magnitude lower than the gradient of Reynolds stress ($\sim 10^8 m/s^2$) previously measured in TJ-II [6]. We note that this position has not yet reached the transport barrier region which is at $\rho < 0.85$ in TJ-II [7]. It may be interesting to have measurements of Maxwell stress further inside the plasmas in TJ-II in the future. The cross-power spectrogram in the right panel of figure 5 shows the Maxwell stress is mainly due to the fluctuation of magnetic field at low frequencies.

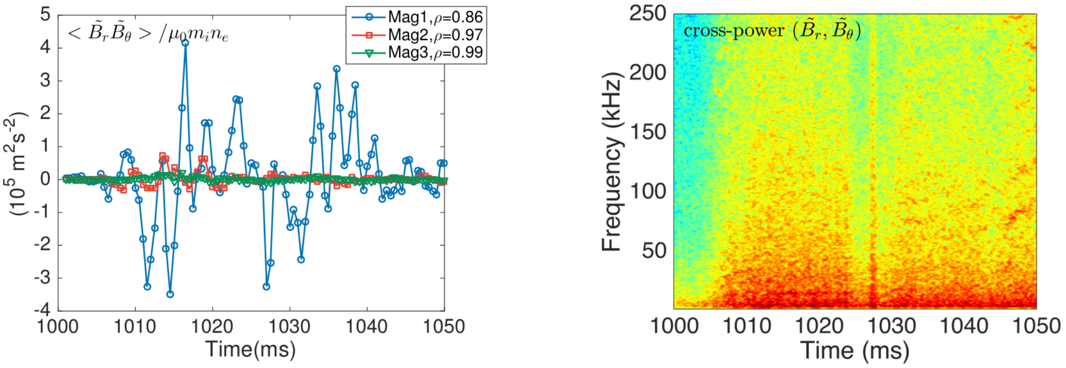

Figure 5. Time evolution of Maxwell stresses (left), and the cross-power spectrogram $\tilde{B}_r$ and $\tilde{B}_\theta$ (right).

IV. Conclusion

We have conducted electromagnetic measurements of plasma turbulence in the TJ-II stellarator with the electromagnetic probe up to the position of $\rho = 0.86$. We found that magnetic fluctuation and Maxwell stress increase radially inwards; in the proximity of L-H transition, a significant gradient of Maxwell stress was observed at the plasma edge. The value is about one order of magnitude lower than previously measured Reynolds stress [6], however, considering the measurement position was outside the transport barrier [7], it would be interesting to measure the Maxwell stress further inside the plasmas in TJ-II in the future.

Acknowledgements

This work was supported by the European Commission and carried out within the framework of the Erasmus Mundus International Doctoral College in Fusion Science and Engineering (FUSION-DC). This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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