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ELM-like Transport Events in TJ-II Stellarator

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1. INTRODUCTION

The transition from low confinement mode (L-mode) to high confinement mode (H-mode) in magnetic traps is normally accompanied by the appearance of a periodic phenomenon known as Edge Localized Modes (ELMs)[1]. These events manifest themselves as an increase in H_α emission, large MHD activity and a modification of the edge profiles, which represents a temporary breakdown of the H-mode edge confinement barrier, with the expulsion of plasma particles and energy. This work is devoted to the study of the recently observed MHD related events in the TJ-II stellarator that resemble the characteristics of the ELMs observed in tokamak and in the W7-AS stellarator [2] in the L mode phase prior to the H mode and were described as ELM-like modes.

2. CHARACTERIZATION OF ELM-LIKE EVENTS IN TJ-II STELLARATOR

ELM-like events have been observed in a majority of discharges with heating power above 300 kW. In these discharges, the central electron temperature is $T_e(0) \leq 1.2$ keV, the line averaged density ranges between (0.7-1.2) $\times 10^{19}$ m^{-3}, and the stored plasma energy reaches values up to W_{dia} = 1.5 kJ. The particle confinement time is about (5-8) ms and the global energy confinement time is greater than 4 ms [3].

Figure 1 shows the evolution of a few ELM-like events on an expanded time scale. In most of the cases, a coherent magnetic precursor oscillation with high frequency ($f \approx 30$ kHz) can be observed prior to an ELM-like event. The beginning of the magnetic burst is immediately followed by an increase in the outermost ECE channel signal and a decrease in the electron temperature measured by ECE in the inner plasma region. This fact indicates that the electron temperature profile locally flattens and a pivot point is well defined at temperature around 150 eV ($r_{eff} \approx 0.12$ m), as can be clearly seen in figure 1. After the local flattening of the temperature profile, a cold pulse propagates inwards up to the plasma centre and it can produce a drop of up to 100 eV in the central temperature. The cold pulse has a characteristic propagation time with a typical diffusive transport coefficient of χ = (2-4) m^2/s. This value is in good agreement with neoclassical calculations [4] and with that obtained using the predictive transport code Proctr [5].

The appearance of the pivot point in the electron temperature profile is followed by an increase in H_α emission (see figure 1), suggesting a sudden increase of the outward particle flux. Simultaneously, Langmuir probes located at the limiter radius measure an increase in the electron temperature. Fast changes in electron density profile at the edge (r_{eff}>0.14) are also observed, but starting right after the H_α burst. The ELM-like activity also has strong influence on impurity behaviour. In particular, the C V line emission that peaks about r_{eff} = 0.1 m in TJ-II plasmas, shows a clear increase during ELM-like events.

The characteristics above described indicates that the impact of the instability is localized at the pivot point. The radial location of the pivot point coincides with the region where the electron density profile presents a shoulder, which could suggest that a sufficiently steep pressure gradient is needed in order to trigger the instability.

The temporal evolution of an electron temperature profile during a single ELM-like event has obtained from ECE signals. The temperature gradient observed where instability appears (at the pivot point position) is typically 6 keV/m prior to the instability and this is reduced by a factor of two during the ELM-like event.

Electron heat conductivity is estimated using the predictive transport code Proctr for the instant before the instability is triggered. Taking the electron heat transport equation and assuming that the density and the radiated power profiles do not vary strongly during the instability development, the electron heat conductivity during the instability, χ, is given by:

$$\chi(r,t) \approx \chi(r,t_0)\left(\frac{\partial T(r,t_0)}{\partial r}\right)\left(\frac{\partial T(r,t)}{\partial r}\right)^{-1} - \\ -\frac{1}{r\,n(r)}\left(\frac{\partial T(r,t)}{\partial r}\right)^{-1}\frac{3}{2}\int_0^r n(r')\left(\frac{\partial T(r',t)}{\partial t}-\frac{\partial T(r',t_0)}{\partial t_0}\right)r'\,dr'$$

where T and n are the electron temperature and density, t_0 is a given time prior to instability onset and t is a time during instability development, close to t_0. From preliminary Li beam density measurements [6], it is observed that the electron density profile (at r_{eff} > 0.13 m) is almost frozen during the instability development (when changes in temperature take place) therefore ensuring that the former assumption used for the thermal conductivity estimation is accurate.

During an instability, the local value of heat conductivity at the pivot point is twice that of the value before the ELM-like activity, as depicted in figure 2. Therefore, the process could be explained as follows: an instability causes a sudden enhancement of the electron heat conductivity which results in a flattening in the electron temperature profile in this narrow region. The decrease in the electron temperature gradient results in a modification of the pressure gradient that in turn causes a relaxation in the instability. The conductivity then takes values similar to the former one and the temperature profile is restored. The time scale of the relaxation is longer than the instability development time.

3- DISCUSSION ON DESTABILIZATION MECHANISMS

The ELM-like modes consist of two connected (although possibly independent) events: the first event is related to the magnetic oscillations observed in the Mirnov coils. The analysis of the radial dependency of the amplitude in the Mirnov coil signals indicates that the phenomenon is related to a low order resonant mode. The vacuum rotational transform is 1.51 at the magnetic axis and increases up to 1.61 towards the edge. Given this rotational transform profile, we can be confident that it is an m=2, n=3 mode, where m and n are the poloidal and toroidal mode numbers, respectively. On another hand, in the discharges analysed for this work, up to -1 kA of toroidal current in the plasma has been measured by the Rogowski coil. Equilibrium calculations performed with the VMEC code [7], assuming a parabolic net toroidal current density profile, show that the 3/2 resonance is inside the plasma, where both profiles are presented. This possibility is also supported by the fact that the ECE signal, corresponding to an effective radius of r_{eff} = 0.088 m, shows the strongest correlation with the magnetic signals, as can be observed in figure 3.

The second event is the ELM-like mode itself which is clearly observed in the modification of the electron temperature profile and, later on, in the H_α signal. This mode is radially located in a region with a relatively high pressure gradient. In the frame of one fluid MHD model, the ELM-like mode detected at r_{eff} =0.12 m could be related to a resistive ballooning instability, which presents the lowest pressure gradient threshold to be destabilised. Further theoretical and experimental work must be done to fully understand the nature of the observed events. A scan on the magnetic configuration, by progressively changing the rotational transform profile around the 3/2 resonance, will be performed in order to clarify the role of this resonance relative to the ELM-like events.

4. CONCLUSIONS

Large ELM-like activity has been recently observed in TJ-II, in plasmas with relatively high plasma stored energy (about 1kJ). The plasma develops bursts of magnetic activity (observed in the Mirnov coils signal), followed by a large and distinct spike in the H_α signal.

Transport analysis shows an important enhancement of the electron thermal conductivity in the radial location of the ECE-pivot point position. The outward particle flux is enhanced and, because of that, plasma pressure gradient will probably decrease, producing the relaxation of the instability.

The nature of the MHD instability that triggers these modes is under study, but preliminary results show that a m=2, n=3 resonant mode interacting with a resistive ballooning instability located at the pivot point is the most probable cause for the event development. The analysis of the properties of the plasmas where these instabilities are present in TJ-II is under investigation and future work must be done in order to clarify this point.

Figures

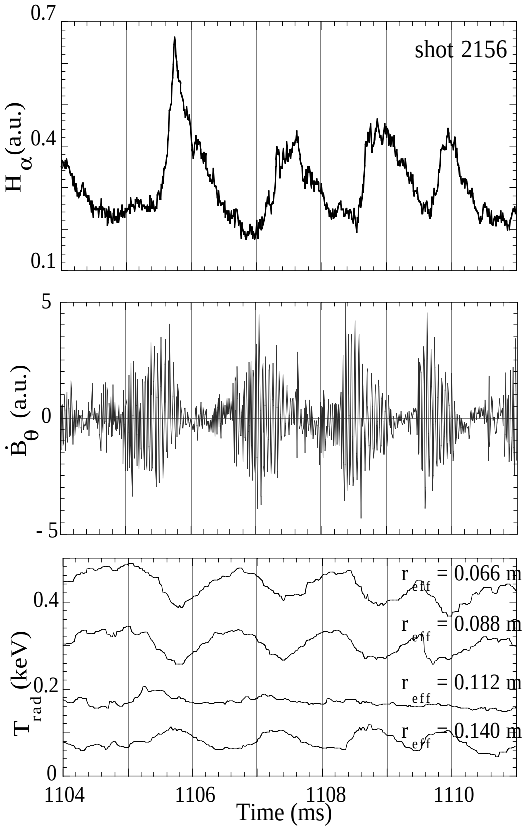

Figure 1. Time traces of: (a) H_a signal, (b) Mirnov coil signal and (c) ECE signals at four radial positions showing ELM-like activity in TJ-II shot #2156.

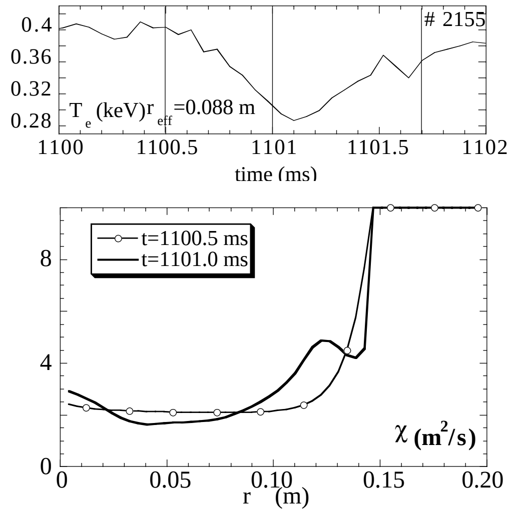

Figure 2. Electron conductivity profile for the evolution of the single ELM-like event.

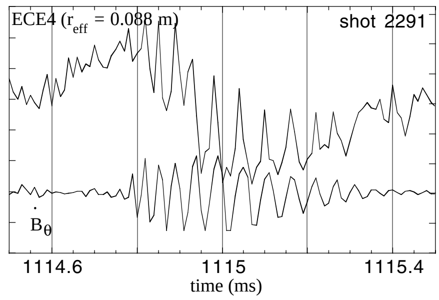

Figure 3. Temporal evolution of one of the ECE channels (corresponding to r_{eff} = 0.088m) and of the Mirnov coil signals during an ELM-like event, in discharge #2291.

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