Investigation of non-linear temperature oscillations in Tore Supra

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Abstract A database and a scaling expression for the non-linear temperature oscillations (TO) was analysed and established in non-inductive plasmas in Tore Supra. Analysis shows that very low plasma loop voltage (V_p) is a necessary condition for the TO. The TO amplitude decreases with increasing TO frequency, plasma density (n_e) and V_p, whereas it increases with the increasing plasma temperature (T_{e0}), internal inductance (l_i), width of driven current profile (δ). It is found that TO plasmas can be achieved in both normal shear and reversed shear configuration and that TO appears mainly for shear values of $-0.45<s_0<0.26$. Furthermore, TO amplitude in reversed shear is larger than that in positive shear discharges.

1. Introduction One of the scenarios for ITER operation is the long pulse discharge in which the plasma current is mainly or totally sustained by non-inductive current. The characteristics of the non-inductively driven current are in general quite sensitive to electron temperature and density profile and simultaneously the shape of current profile may also affect the energy confinement. Non-linear temperature oscillations (TO), understood to be an incomplete internal transport barrier (ITB) transition, have been observed in Tore Supra [1-3], and, in different experimental conditions, in TCV [4] and DIII-D [5]. For the regime observed on Tore Supra (also called the O-regime), the most plausible explanation of this phenomenon is that the plasma current density and the electron temperature evolve as a nonlinearly coupled predator-prey system [1]. In Ref.3, the mechanism for triggering or suppressing the oscillation is investigated in detail. It is reported that magnetic shear perturbations and modifications of the heat transport turn out to be the central parameters governing the dynamics of the O-regime. Here, we investigate the dependence of TO on various plasma parameters.

2. Dependence of TO on plasma parameters Since TO are related to plasma confinement, it is necessary to investigate the dependences of TO amplitude on parameters such as loop voltage, central temperature, density, TO frequency, current profile, and so on. The data used for the analysis consists of 3 parts: LHCD plasma, LHCD + ICRF plasma, and LHCD+ECCD plasma. The database for TO, including ~70 discharges, is analyzed by the combination of

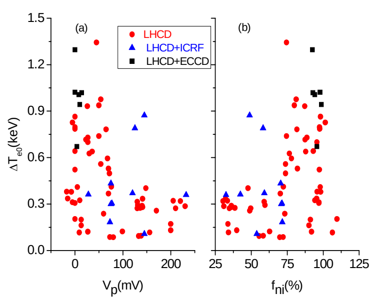

Fig. 1 TO amp. *vs* V_p and f_{ni}

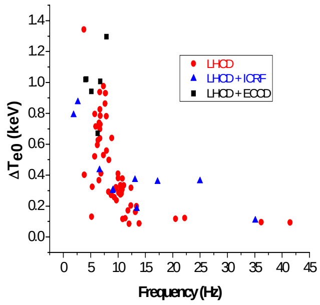

Fig. 2 TO amp. *vs* frequency

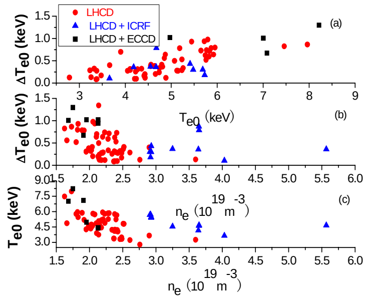

Fig. 3 TO amp. *vs* T_{e0} and n_e

experimental data and quantities (eg., safety factor, magnetic shear and heat transport) reconstructed by the integrated modelling suite of codes CRONOS [6].

2.1 Effect of V_p on TO Figure 1(a) shows the TO amplitude and the corresponding loop voltage. It is seen that the TO are usually obtained in low loop voltage discharges (almost fully non-inductive) and the TO amplitude decreases with increasing loop voltage. This is mainly because TO are a result of nonlinear coupling between plasma current density and electron temperature. The lower the loop voltage, the larger the non-inductive driven current, and hence the stronger the coupling between current and temperature. This is consistent with the dependences of TO amplitude on the non-inductive current fraction (f_{ni}) (see Fig. 1(b)).

2.2 Effect of frequency on TO The relationship between TO amplitude and TO frequency is shown in Fig.2, indicating that the amplitude decreases with increasing frequency. This confirms the trend already discussed in Ref. [1], but now on the basis of a significantly extended data base.

2.3 Effect of T_{e0} and n_e on TO The dependence of TO amplitude on central temperature (T_{e0}) is displayed in Fig.3 (a), showing that the amplitude increases with increasing T_{e0}. Since the O-regime is a result of coupling between plasma current density and temperature, it is natural that electron temperature will affect TO. The effect of the central line averaged plasma density (n_e) on TO amplitude is plotted in Fig.3 (b). It is shown that with increasing density, the oscillation amplitude decreases. The possible reason for this is that with increasing density, the temperature decreases (see Fig.3 (c)). Another possible explanation is that with increasing density, the loop voltage increases and the current profile could be modified.

2.4 Effect of current density profile on TO In highly non-inductive regime, the current density profile is mainly given by the LHCD driven current, which depends on temperature. LHCD driven current profile, characterized experimentally by the half with of hard X-ray

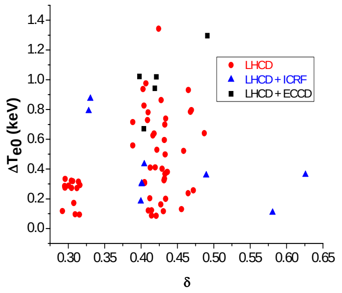

Fig. 4 TO amp. *vs* δ

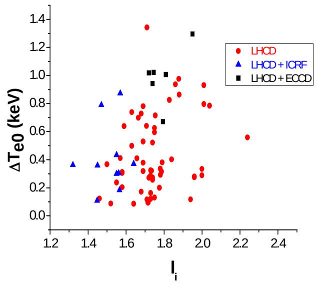

Fig. 5 TO amp. *vs* l_i

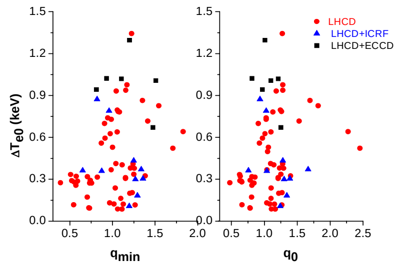

Fig. 6 TO amp. *vs* q_{min} and q_0

profile (δ), is dominant in determining current profile, hence affecting oscillation. The relationship between TO amplitude and δ is plotted in Fig. 4, showing that TO amplitude increases with increasing δ in LHCD case. The internal inductance (l_i) is a global parameter related to the width of the current density profile. The dependence of TO amplitude on l_i is plotted in Fig.5, suggesting that the amplitude increases with increasing l_i. This means that the more peaked the current profile, the larger the oscillation. The safety factor q is another parameter associated with the current profile. The dependences of TO amplitude on q, including the safety factor at the minimum q (q_{min}) and the factor at the center (ρ=0.1) (q_0), are plotted in Fig.6. The magnetic shear s is one of key parameters connecting current profile and heat transport. The dependence of TO amplitude on s_0 is investigated and plotted in Fig. 7(a). As clearly shown on the figure, the TO plasma can be obtained in both positive and reversed shear plasma and TO appear mainly for shear values of $-0.45<s_0<0.26$. Further investigation shows that the amplitude is slightly larger in the reversed shear plasma. This possibly happens because in the reversed shear plasma the heat transport is lower than that in the positive shear plasma (see Fig.7(b)) .

2.5 Effect of RF power on TO RF power (P_{RF}) affects plasma temperature and current profile, hence influencing TO. The dependence of TO on P_{RF} is plotted in Fig. 8(a). In LHCD and LHCD + ECCD cases, oscillation amplitude increases with P_{RF}, whereas in LHCD + ICRF case the variation of TO does not. A possible reason is LHCD and ECCD both mainly modify current profile, but ICRF mainly heats the plasma. Another possible explanation is that P_{ICRF} is much larger than P_{ECCD} and P_{LHCD} (Fig. 8 (b)), leading to different plasma characteristics.

3. Scaling expression A multiple variable fit expression has been found by applying linear regression to the experimental data base. TO are related to plasma temperature, plasma transport, current profile mainly dominated by RF driven current profile in the discharge. The following scaling function has been obtained: $\Delta T_{e0}/T_{e0}=0.145\ I_p^{1.76}\ l_i^{1.76}\ \delta^{0.68}\ q_0^{0.4}\ f_{RF}^{0.03}\ (\exp(s_0))^{-0.7}$. The comparison between the scaling law and experimental data is shown in Fig.9. Although there is a slightly larger scattering for LHCD + ICRF and LHCD + ECCD, the experimental data are consistent with the scaling law for the 3 cases. The reason for the large scattering is possibly that some parameters are not taken into account in the fitting function.

4. Conclusion A database and a scaling function for the TO was investigated and established with LHCD only and LHCD plus ICRH and/or ECCD in Tore Supra. Analysis shows that dominant non-inductive current is required for this plasma regime. The TO amplitude decreases with increasing TO frequency and n_e, whereas it increases with increasing T_{e0}, l_i, and δ. It is found that TO plasmas can be achieved in both positive and reversed shear configuration and that TO appears mainly for shear values of $-0.45<s_0<0.26$. Investigations show that TO amplitude in the reversed shear is larger than that in the positive shear due to the lower transport in the former case. Further is needed to complete this preliminary study.

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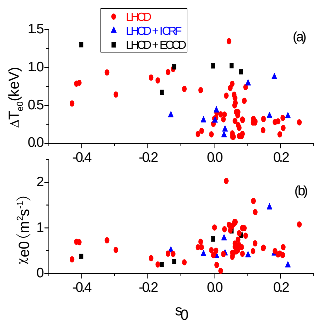

Fig. 7 TO amp. and χ_{e0} *vs* s_0

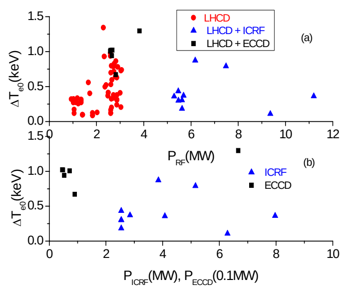

Fig. 8 TO amp. *vs* P_{RF}

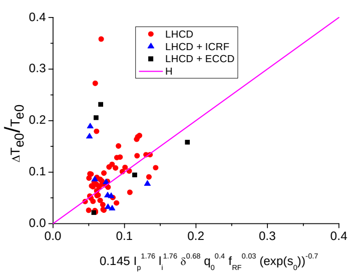

Fig. 9 Fitting and data point