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Test of q comb model on electron ITBs in electron heated JET discharges

G.M.D. Hogeweij[1], M.R. De Baar[1], E. Min[1] and contributors to the EFDA-JET work programme

[1] *FOM Instituut voor Plasmafysica 'Rijnhuizen', Associatie EURATOM-FOM, Trilateral Euregio Cluster, P.O.Box 1207, 3430 BE Nieuwegein, The Netherlands*

1. Introduction

Tokamak regimes where the heat transport in the plasma interior is reduced due to the presence of an internal transport barrier (ITB) have been investigated on many experimental devices, see e.g. [1, 2, 3, 4].

The magnetic structure, i.e. the magnetic shear (s) profile and/or the safety factor (q) profile, appears to play an important role in the physics of the electron ITB (eITB). In this paper a model is used based solely on q. Simulations are presented of JET discharge 53521, one of the best performing JET discharges with strong ITBs so far [5].

2. Experimental Data

The scenario of discharge 53521 consists of a pre-heat phase during the current ramp-up, with switch-on of Lower Hybrid Current Drive (LHCD) very early in the discharge, at 1 s, followed by a main heating phase where LHCD, ICRF and NBI are used; see Fig.2. The pre-heat phase is characterized by low density (n_e) and $T_e > T_i$; during the main heating phase a strong increase of n_e is observed and $T_i > T_e$. Analysis with a dimensionless criterion based on the ratio of the ion gyro-radius to the local gradient scale length [6], shows that a strong eITB was present in this discharge, both in the pre-heat and the main heating phase [5].

Motional Stark Effect (MSE) data are available only at two time slices, 4.3 and 4.6 s; the thus inferred q profiles show $q_{\rm min} \simeq 3.0$ and 2.75, respectively. Alfvén wave cascades (ACs), excited by the ICRH-accelerated ions, are observed at t = 4.7 (n = 3), 5.1 ($n = 5$) and 5.4 (n = 6 or 7) s [7]. The most likely sequence is $q_{\rm min} = 2.67, 2.6, 2.5$ at $t = 4.7, 5.1, 5.4$ s, respectively. This fits well with the MSE data. Moreover, no more ACs are observed after 5.6 s, indicating that $q_{\rm min}$ does not cross any low order rational values after this time, i.e. that q is frozen effectively.

3. The Model

The q comb model prescribes the electron thermal diffusivity (χ_e) as a simple function of the safety factor q, with barriers near low rational values of q [8]. Single, fixed, functions $\chi_e(q)$ were able to describe electron thermal transport for large sets of similar RTP discharges with on- and off-axis heating [9]; also TEXTOR discharges with EC heating were successfully modelled [10]. Wendelstein 7AS showed very similar results [11].

The model was also able to reproduce electron ITBs in Optimized Shear (OS) JET discharges [12], see Fig.1. At the time of that analysis there were no JET discharges with strongly reversed shear (RS) available. During the 2001 experimental campaign such discharges have been made where LHCD sustained a RS configuration. The chosen discharge 53521 is a good example of this class.

The q comb model has been implemented in the JETTO transport code. The next section presents results of simulations with this model of discharge 53521.

4. Modelling results

The experimental data show that the eITB is only clearly seen in the $s < 0$ region of the plasma. Therefore the q comb model has been modified such that the barriers near low rational q take two strengths: strong barriers for $s < 0$, weak barriers for $s > 0$. Fig.3 shows the $\chi_e(q)$ function that has been used for shot 53521.

As in the q comb model electron transport is completely determined by the magnetic structure, it is essential to model the current density (j) correctly. An important part of j is driven by LHCD and NBI (j_{LH}, j_{NB}); those have been calculated from the experimental data by the DELPHINE and TRANSP code, respectively [13]. Fig.4 shows j_{LH} and j_{NB}, plus the experimental (dashed) and modelled (full lines) profiles of bootstrap current (j_{bs}) and j, during pre-heat and main heating phase (upper and lower panel, respectively). The sharp barriers in the model cause sharper local features in j and j_{bs}; apart from that, the model follows the experimental profiles reasonably well during the pre-heat phase, and very well in the main heating phase.

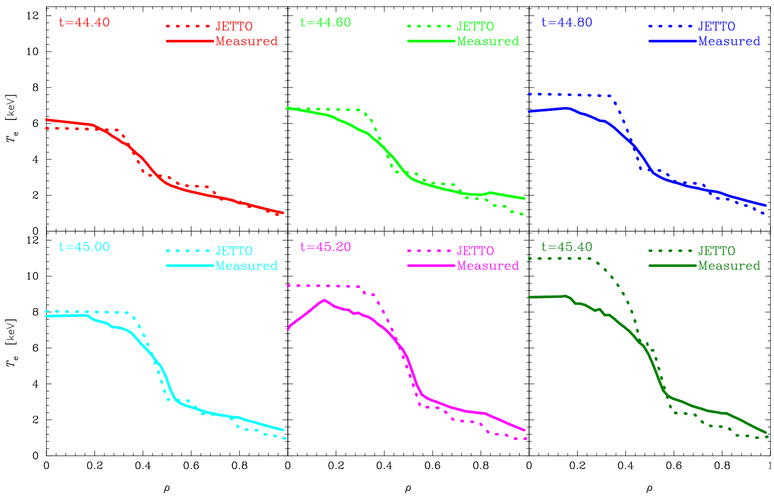

Figure 1: *Simulation of Optimized Shear JET discharge 49017 with the q-comb model, see [12].*

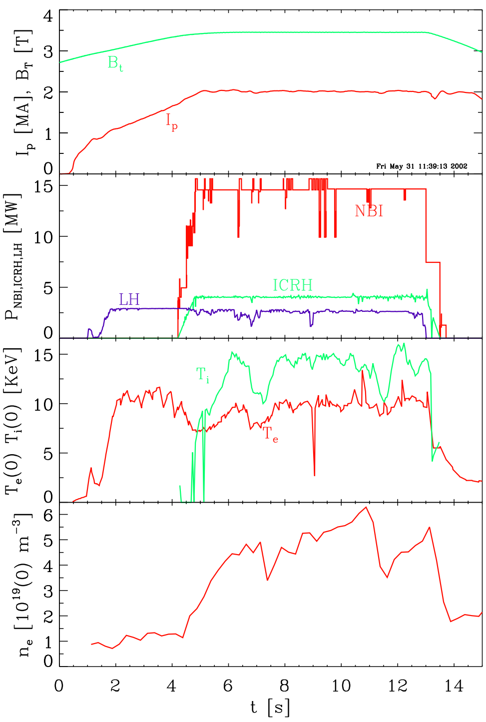

Figure 2: *Scenario of discharge 53521, showing I_p, B_t, input powers (P_{NBI}, P_{LH} and P_{ICRH}), and central T_e, from ECE, T_i, from charge exchange, and n_e, from Lidar.*

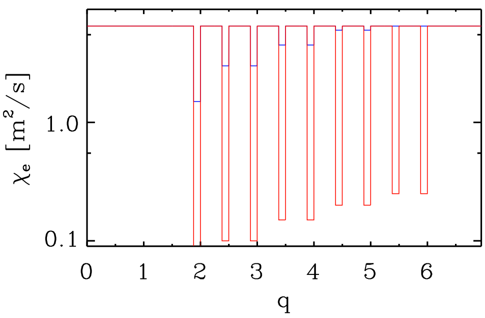

Figure 3: *Profile of χ_e as function of q. In red the profile in used where $s < 0$; in blue the one used where $s > 0$ (the difference is only in the barriers).*

Fig.5 compares time traces of $q_{\min}$ and $\rho(q_{\min})$ as calculated from experimental data (using neo-classical current diffusion, taking non-diffusive contributions into account) with the modelling results. Also shown are the data points from MSE and given by the ACs. If we trust the latter values, then the q profiles based on experimental data show too low values of $q_{\min}$, and the modelling result too high values. Both agree very well after 6.5 s; both do not cross $q = 2$ as predicted by the absence of ACs after 6.5 s.

As for T_e, Fig.6 compares the time evolution of $T_e(0)$, and Fig.7 compares T_e profiles at some typical times. The model performs quite well during pre-heat but underestimates T_e during the main heating phase.

The observed crashes of T_e during pre-heat are reproduced well in the simulations. In the simulations they are caused by the alternating presence and absence of a low shear region near $q_{\min}$. E.g., q evolves from a profile with a low shear region near $q_{\min} \simeq 4$ at 3.5 s (strong barrier) through a profile without such region (no strong barrier), to a profile with a low shear region near $q_{\min} \simeq 3.5$ at 4.3 s (again strong barrier).

5. Discussion and Conclusions

The important role of the magnetic topology in the triggering and sustainment of ITBs is recognized in theory. E.g. simulations of turbulence reveal the importance of low order rational q values [14, 15]. The triggering role of low order rational q was indeed observed in JET, see e.g. [16, 17]

The standard q comb model, with barriers of equal strength for $s < 0$ and $s > 0$ gave completely wrong T_e profiles and a much too slow q evolution. I.e., it was essential to assume a difference between the region with $s < 0$ and $s > 0$.

With this additional assumption, the q comb model can quite well simulate the T_e and q evolution during the preheat phase. During the main heating, the q evolution is still followed nicely; however, the experimentally observed T_e is significantly higher than given by the modeling. It appears that an additional transport reduction mechanism, in particular in the weak positive shear region, plays a role in this phase. Another indication of this is the strong peaking of n_e. This peaking was not observed in OS discharge 49017. This might explain the success of the q comb modelling for the latter shot.

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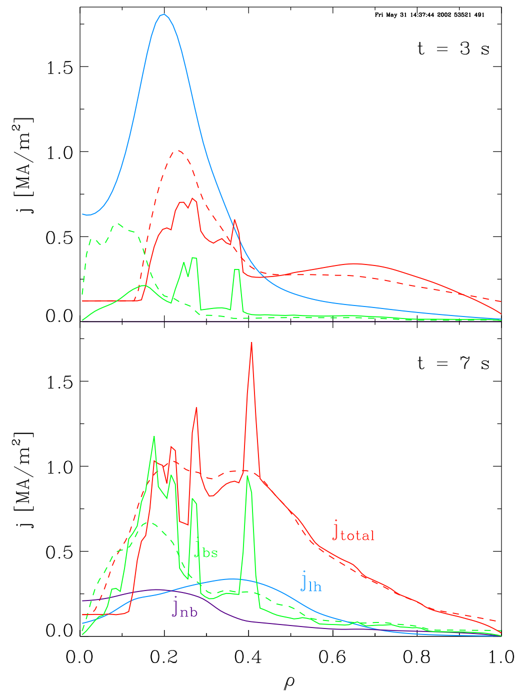

Figure 4: *Current density (j_{total}, red) during pre-heat (upper) and main heating (lower panel) inferred from experimental data (dashed), compared with the modelling results (full lines). Also shown are the non-inductive contributions j_{LH} (blue, dominant during pre-heat), j_{NB} (pink) and j_{bs} (green, dominant in main heating phase).*

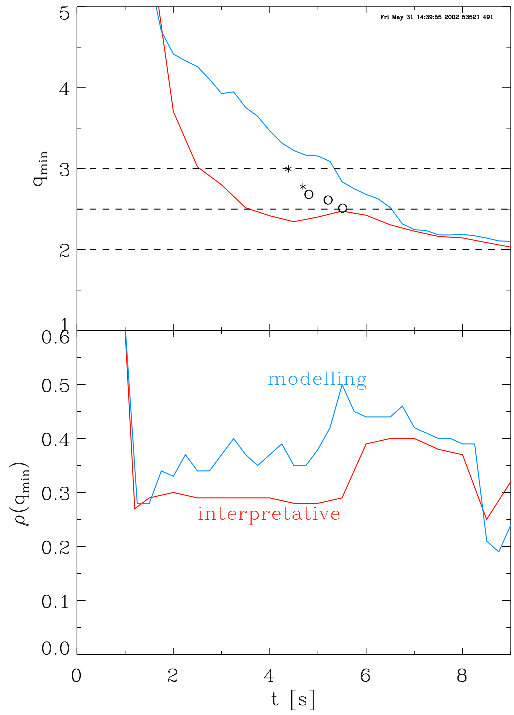

Figure 5: *Time traces of $q_{\rm min}$ and $\rho(q_{\rm min})$ from experimental data (red) and modelling (blue). Also shown are the $q_{\rm min}$ values from MSE (asterisks) and as inferred from Alfvén wave cascades (circles).*

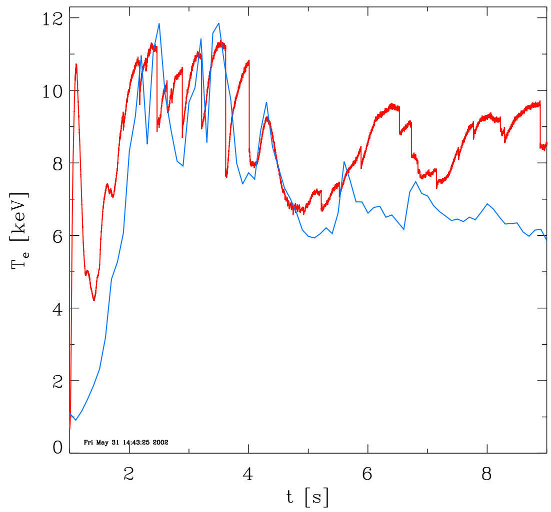

Figure 6: *Time evolution of $T_e(0)$ as experimentally observed (red) and simulated (blue).*

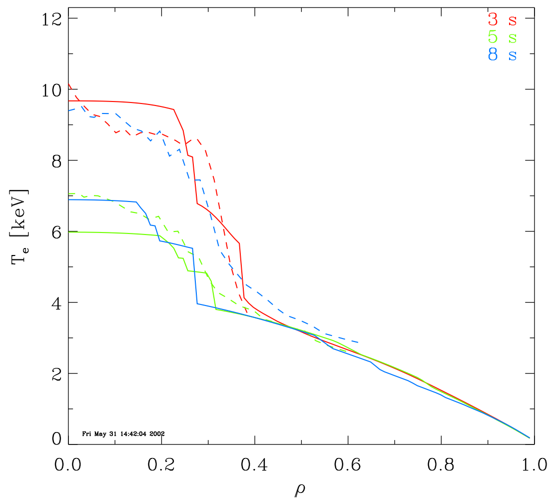

Figure 7: *Experimental (dashed lines) and simulated (full lines) T_e profiles at 3, 5 and 8 s.*