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Influence of rotational shear on triggering and sustainment of internal transport barriers on JET

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**See the appendix of F. Romanelli et al., Fusion Energy Conferences 2008 (Proc. 22nd Int. FEC Geneva 2008) IAEA, 2008*

1. Introduction

Plasmas with improved confinement by an Internal Transport Barrier (ITB) are considered in the Advanced Tokamak scenarios for ITER. Dedicated pulses to study the effect of poloidal (v_θ) and toroidal (v_ϕ) rotation velocities on the triggering and sustainment of ITBs have been carried out on JET. A new instrument has recently been added to the suite of charge exchange spectrometers allowing v_θ measurements up to 10 ms in the ITB region [1], which is the same temporal resolution as for the v_ϕ and ion temperature (T_i). A torque and power scan was performed. Pulses with reversed and monotonic *q*-profiles are compared to investigate the role of magnetic shear on the ITB triggering and growth.

2. Experimental results and discussion

A series of JET plasmas were run at B_t/I_p=2.2T/1.8-1.9MA and central line averaged density of 7-8e^{19} m^{-2}. The NBI power was varied between 7 MW and 15 MW and the ICRF heating power that was coupled to the plasma varied between 1.0 MW and 3.3 MW. In some of the discharges 2 MW of LHCD was applied during the current ramp-up phase to create a reversed *q*-profile. Alfvén cascades were observed in these discharges during the entire main heating phase indicating shear reversal.

2.1 Torque and power scans

The total torque was varied between 6 and 17.5 Nm and total power between 10 and 19 MW. It has been found that the largest T_i gradients were created in plasmas with negative magnetic shear, a total torque of 15-16 Nm and 18 MW of additional heating power. The maximum ρ^*_{Ti} value, a normalized local gradient scale length that indicates the existence and performance of an ITB on JET [2], reached values up to 0.038, well above 0.014, the empirical threshold for an ITB on JET.

2.2 Role of poloidal rotation velocity on triggering of the ITB

With the improved time and spatial resolution of the diagnostic a detailed study was performed to investigate the causality question between an increase in poloidal rotation velocity and the triggering of the transport barrier. In the majority of the pulses the start of the T_i increase and the excursions in v_θ are simultaneous (within the 10ms time resolution).
As soon as an ITB is triggered v_θ increases in the region with the strongest T_i gradient, which helps to sustain the barrier, as discussed in [3]. However the discharge for which T_i, v_ϕ and v_θ time traces are shown in figure 1, does show an increase in v_θ 200ms earlier than the temperature rise, which indicates the onset of the ITB. The time t=5.05 s when v_θ starts to increase, coincides with a large Type-I ELM and a dip in the central part of the T_i profile. No strong mode activity has been detected between t=5.05s and t=5.25s. At the start of the ITB (t=5.25 s) an n=1 mode is present in the plasma, which persists for over 500 ms. During the ITB phase the ELMs are Type-III. Alfvén cascades are seen throughout the shots. The EFIT reconstruction, including MSE, Faraday rotation, pressure and electric field effects, indicates that q_{min}=2 at t=5.15s. In figure 2 profiles of T_i, ω_ϕ and v_θ are shown before and during the ITB phase. The increase in poloidal rotation is localized to R_{mid} = 3.35 – 3.60m (corresponding to ρ=0.40 – 0.70), and a maximum value of 65 km/s is reached at the peak of the barrier, with central a T_i of 14 keV. In figure 3 and 4 the radial electric field (E_r) has been calculated at the start of the rise in poloidal rotation. The largest E_r shear is located in the region ρ=[0.40 -0.50], where later on the transport barrier develops. The localized spin-up in v_θ is larger than the neoclassical prediction by NCLASS for carbon impurity ions. The high poloidal rotation velocity is the reason for the large E_r gradient. It might help to push the shearing rate ($\omega_{\mathbf{ExB}}$) above the linear growth rate of the unstable modes and trigger the ITB. This could explain the existence of a very strong ITB (ρ^*_{Ti}=0.038) in the plasma despite a moderate value of total torque (9 Nm) and input power (14 MW).

2.3 Role of the *q*-profile

In figure 5 profiles of two discharges (shot no. 72737 and 72747) with similar heating power (i.e. 15 – 16 MW of NBI and 1 – 2 MW of ICRH) and total torque (15 – 15.5 Nm) are compared. On the left hand side T_i, v_ϕ, v_θ and *q*-profiles are shown at a time before a sustained ITB is present in the plasma. It can be seen that the rotation and temperature profiles are very similar. For shot no. 72737 the *q*-profile is reversed and q_{min} is still above 2. In shot no. 72747 the *q*-profile is monotonic and the rational surface q=2 is already present in the plasma before the start of the main heating phase. On the right hand side are profiles at a later time (t=6.0s) when the ITB is fully developed. A strong barrier (ρ^*_{Ti} = 0.025) is triggered in shot no. 72737 just after q_{min} hits the rational surface q=2. For the same amount of rotational shear the monotonic *q* case does not develop a sustained barrier, the maximum value of ρ^*_{Ti} is 0.019. Some trigger events are observed in the T_i time traces, which coincide with excursions in v_θ of up to 10 km/s. The values of v_θ are well above the neoclassical predictions, but they do not appear to be sufficient for the growth of a strong barrier.

3. Conclusions

It has been found on JET that a localized spin-up in v_θ can precede the onset of a transport barrier. Consequently, the radial electric field shear is enhanced, which then helps to suppress turbulence locally and to trigger an ITB. This increase in v_θ prior to the triggering of the barrier, is not a common observation in the present database and perhaps not essential. However, when present, it may reinforce other factors that play a role in the triggering such as a rational *q*-surface, MHD activity and a large toroidal rotational shear.

The strongest barriers (corresponding to a ρ^*_{Ti} value > 0.030) were found in plasmas with a reversed *q*-profile and q_{min}=2 for an input power of 17-18MW and a total torque of 15-17 Nm. In plasmas with monotonic *q*-profile ITBs have been triggered, but they were weaker and did not develop large T_i gradients, the maximum value of ρ^*_{Ti} was 0.019.

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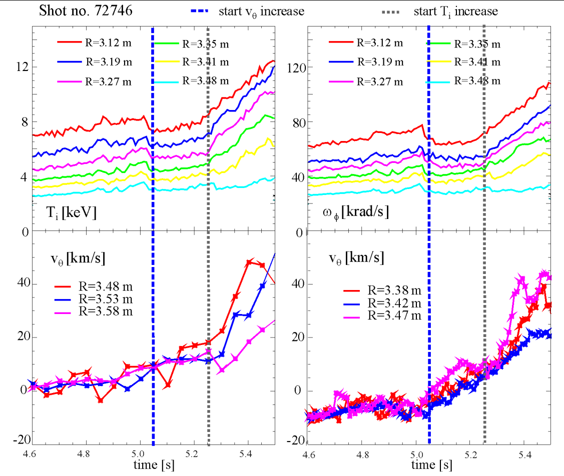

Figure 1: Temporal evolution of T_i, ω_ϕ and v_θ at different radial positions. The v_θ increases precedes the T_i increase by 200 ms.

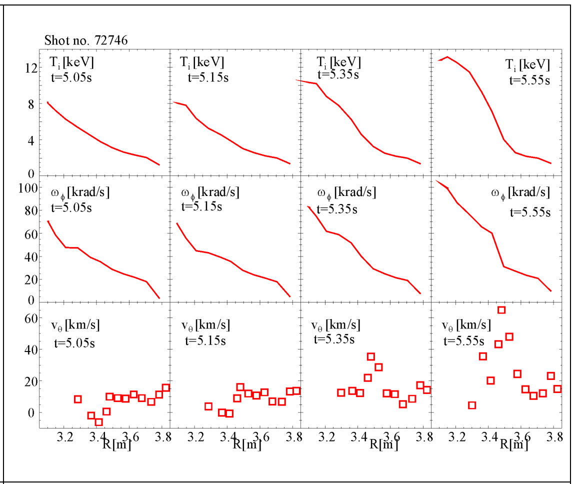

Figure 2: Profiles of T_i, ω_ϕ and v_θ at different times before (t=5.05s, t=5.15s) and during the ITB phase (t=5.35s, t=5.55s).

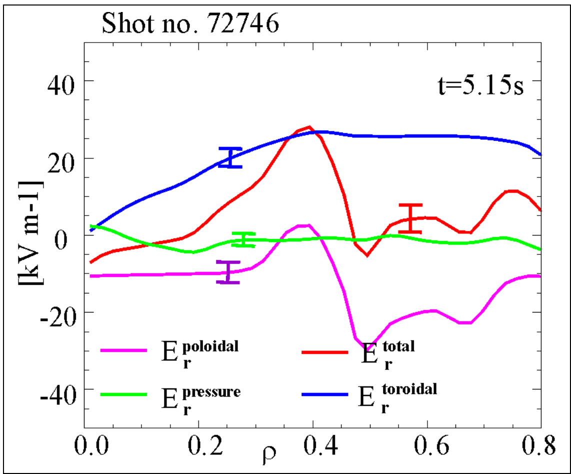

Figure 3: Contributions to E_r profile at a time before the start of the ITB. The localized spin-up in v_θ creates a large gradient in E_r at r=0.40-0.50.

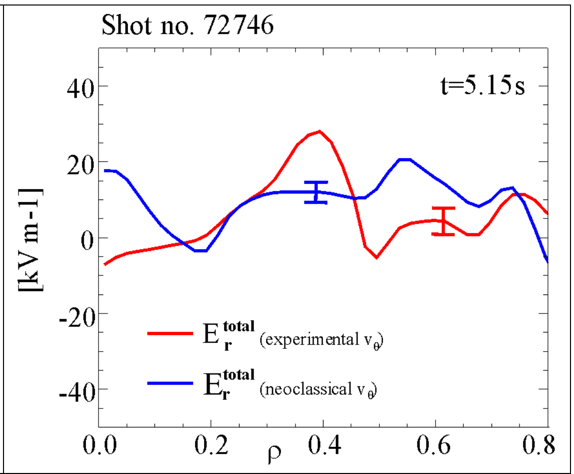

Figure 4: Profile of E_r calculated with the experimental and the neoclassical v_θ.

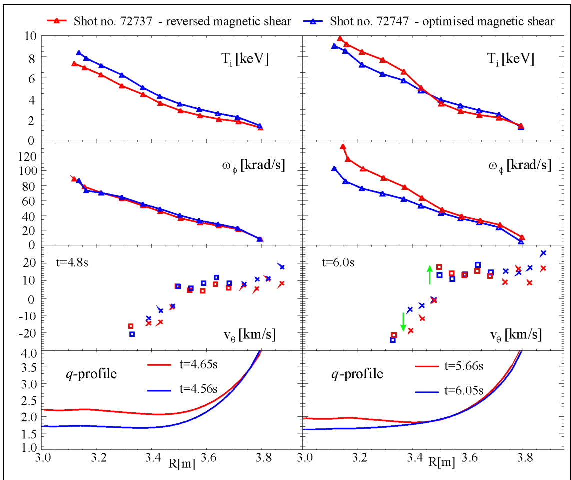

Figure 5: Comparison of T_i, ω_ϕ and v_θ and *q*-profiles for shot no. 72737 and 72747 before (left hand side at t=4.8s) and during the ITB phase (right hand side at t=6.0s). The T_i gradient for shot no. 72737 with reversed *q*-profile and q_{min}=2 is steeper than for the monotonic *q* case. The v_θ profile before the ITB is similar in both plasmas, and spins up with the T_i gradient increase for shot no. 72737 [3].