Role of Toroidal Plasma Rotation in the Dynamics of the Internal Transport Barrier.

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1. Introduction

Recent experiments with Optimised Shear plasma in JET [1,2] revealed some unusual features of the Internal Transport Barrier (ITB) dynamics, which pose a challenge to theory based transport models. Particularly, experiments showed that the width of the ITB, after emergence, expands initially in time until it reaches saturation. Very often this saturation does not lead to a real steady state but is followed by the erosion and sometimes by the complete collapse of the ITB. In order to assess the feasibility of contemporary transport models to reproduce these kind of dynamics, we perform predictive numerical modelling of some of the JET optimised shear discharges. To make the modelling fully self-consistent, we include toroidal and poloidal rotation into the list of simulated parameters. Since toroidal rotation is controlled by a not yet thoroughly understood anomalous viscosity, we first test our model for this viscosity on a number of ELMy H-mode plasma which constitute a $\rho*$ scan. This model was then used to simulate the evolution of the radial electric field and turbulence suppression in the Optimised Shear JET plasmas.

2. Modelling of Toroidal Rotation in ELMy H-mode.

The JET transport code JETTO has been recently upgraded and now includes a self-consistent predictive modelling of the toroidal plasma rotation. The model for the anomalous toroidal viscosity was first tested on a series of well documented JET ELMy H-mode plasmas in D and T which belong to a recent $\rho*$ scan (see Table) [3].

Shot No	Work. Gas	B_{tor}(T)	I_{pl}(MA)	P_{NBI}(MW)	W_{DIA}(MJ)
#42501	D	1	1	5	3
#43132	D	2	2	10	5.5
#42493	D	3	3	10	5.5
#42776	T	1	1	5	3
#42808	T	2	2	10	5.5
#42780	T	3	3	10	8

It is worth noting that unlike many other models, the JET empirical transport model, which uses a combination of Bohm, gyroBohm and ion neoclassical transport coefficients [4] and the boundary conditions at the separatrix, explicitly takes into consideration transport in the region within the edge transport barrier (ETB). We assume that ETB has a width Δ, which might scale either as a banana width of beam ions ($\Delta \approx \sqrt{\varepsilon} \cdot \rho_{\theta i}^{beam}$) or Δ=const. Transport within the barrier is assumed to be ion neoclassical between ELMs. Each ELM is modelled by a short increase of all transport coefficients within the barrier when the pressure gradient

exceeds ballooning stability limit. The results of the modelling are shown on Figures 1,2 and can be summarised as follows.
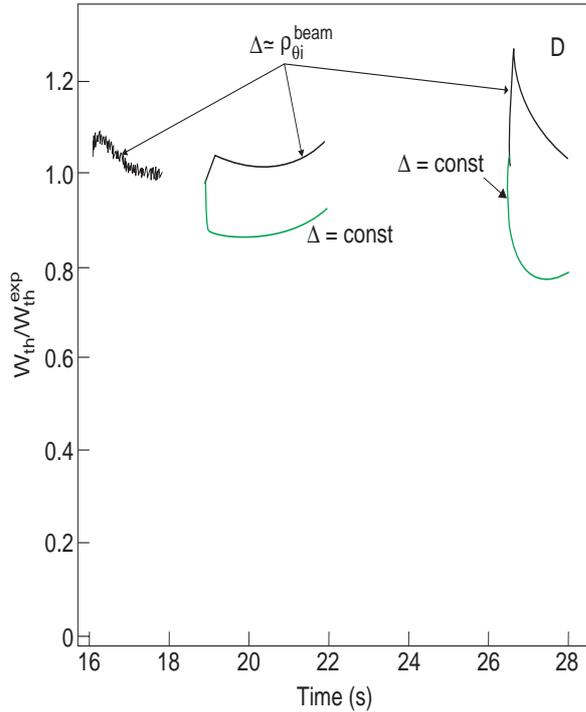

Figure 1. Thermal plasma energy, calculated with JET transport model and normalised on the measured energy, for 1T, 2T and 3T shots in D with either $\Delta \propto \rho_{6i}^{beam}$ or $\Delta = const$.
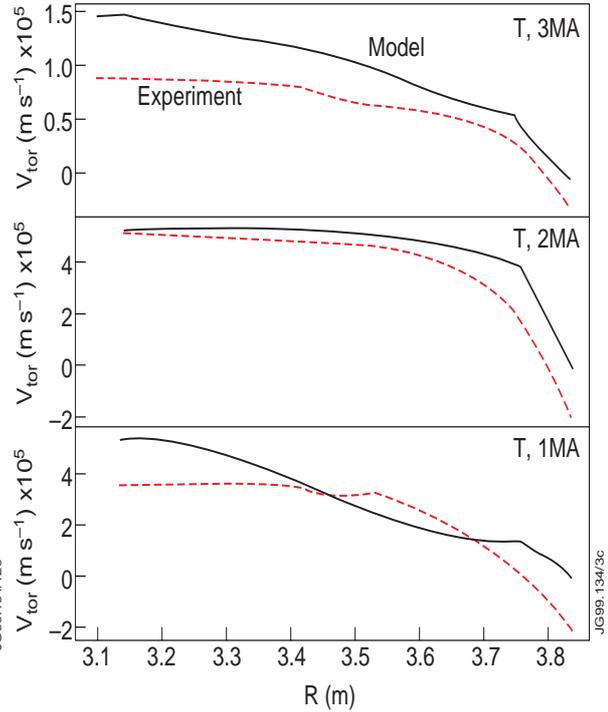
Figure 2. Measured and simulated toroidal rotation profiles for ρ_* scan shots in D with an assumption that $\mu = \chi_i$

The dependence of the ETB width on plasma current is the primary parameter, which controls the energy confinement time in ELMy H-mode. An attempt to use Δ=const leads to a systematic deviation between predicted and measured energy content which increases with the plasma current. The isotope dependence of the ETB width and of the gyroBohm transport coefficients are much weaker and partly compensate each other. Finally, we conclude that the best approximation for a toroidal viscosity is $\mu \approx \chi_i$, although the deviation of the simulated toroidal velocity from experimental profiles is not very sensitive function of μ.

3. Modelling of the Optimised Shear Plasmas.

To make a predictive modelling of the Optimised Shear plasma the transport model [4] was modified to take into account the mechanisms of the turbulence suppression by strong shear in plasma rotation and by a negative/small magnetic shear [5]. In line with our previous results we assume that the long wavelength turbulence only (Bohm component of the transport coefficients, see [5] for details) is suppressed when the following condition is satisfied: $0.1 + s - \alpha \cdot \Omega \le 0$. Here s is magnetic shear, α- numerical constant and:

$$\Omega \equiv \frac{\omega_{E \times B}}{\gamma} \propto \frac{R \left| \frac{(RB_\theta)^2}{B} \frac{\partial}{\partial \Psi} \left[\left(\frac{\nabla n_i T_i}{e n_i} - V_\theta B_\phi + V_\phi B_\theta \right) \frac{1}{RB_\theta} \right] \right|}{V_{th,i}} \qquad (1)$$

It is worth mentioning that now we calculate all three components of the radial electric field in (1) (ion pressure gradient, poloidal and toroidal rotation) in a self-consistent way and

therefore we can evaluate the relative role of these components in the formation of the ITB (we use a neo-classical expression for the poloidal velocity). Some results of this study are shown in the Figures 3-5 and can be summarised as follows. It follows from Figure 3,4 that qualitatively the JET transport model reproduces the main features of the ITB dynamics- its formation, followed by the radial expansion, saturation and further contraction or even collapse of the ITB.
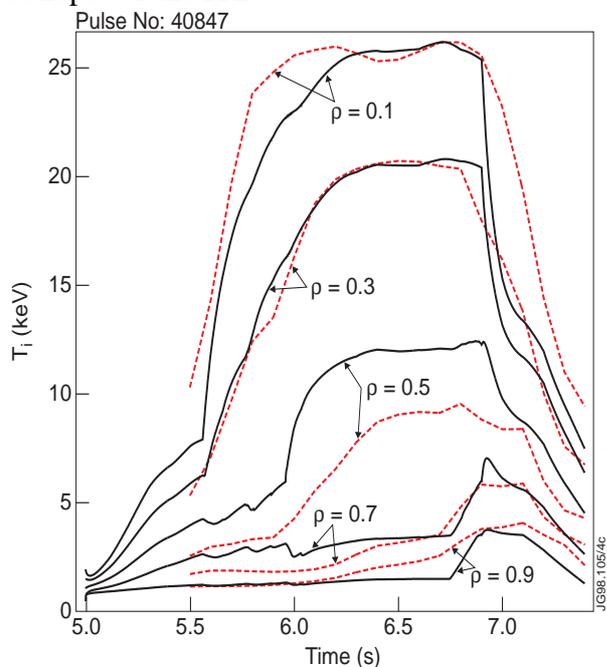

Figure 3. Time evolution of the measured and simulated ion temperature for the shot #40847 with the density evolution, prescribed by experiment.
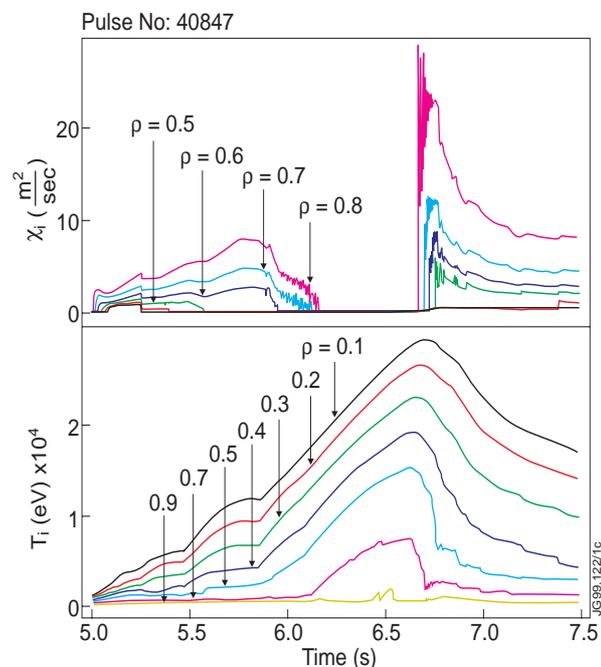
Figure 4. Temporal evolution of the simulated ion thermal conductivity and ion temperature in case of continuous density rise.

The latter event deserves particular discussion since it is often triggered by one or another type of the MHD instability and is sometimes considered not as a transport but rather as MHD phenomenon. Statistical analysis shows, however [6] that in about 40% of these sudden collapses of the ITB no sign of any MHD activity has been observed. The result of our modelling suggests that this event is nothing more than a reverse bifurcation from the state with a wide ITB into the state with either weak, narrow ITB or without any ITB. Three possible reasons for such a bifurcation have been identified in our model. First one might be associated with the evolution of the q-profile (such evolution might decrease the volume, occupied by the negative magnetic shear). Two remaining reasons are associated with the radial electric field evolution. It follows from (1), and from the neoclassical expression for the poloidal velocity, that shear in the plasma rotation is controlled either by the peakedness of the density profile or by the shear in toroidal rotation. In case of JET Optimised Shear plasmas both mechanisms rely on the NBI momentum and particle fuelling and both degrade while the density builds up. Therefore the possible ways to avoid back bifurcation or at least extend the duration of improved confinement include either better control of edge density or an increase in the heating NBI power. Figures 4 shows the relative role of the different terms in the radial electric field for two characteristic times slices- shortly after the emergence of the ITB and shortly before its collapse. We conclude that toroidal rotation is initially the main contributor to the radial electric field, since the two other terms partly compensate each other. However later on the situation become more complicated. As we discussed earlier, as the density builds up, the relative importance of the toroidal rotation decreases (particularly in the

region close to the foot of the ITB, see Figure 4). Since at that time the position of the ITB is mainly controlled by the density peakedness.
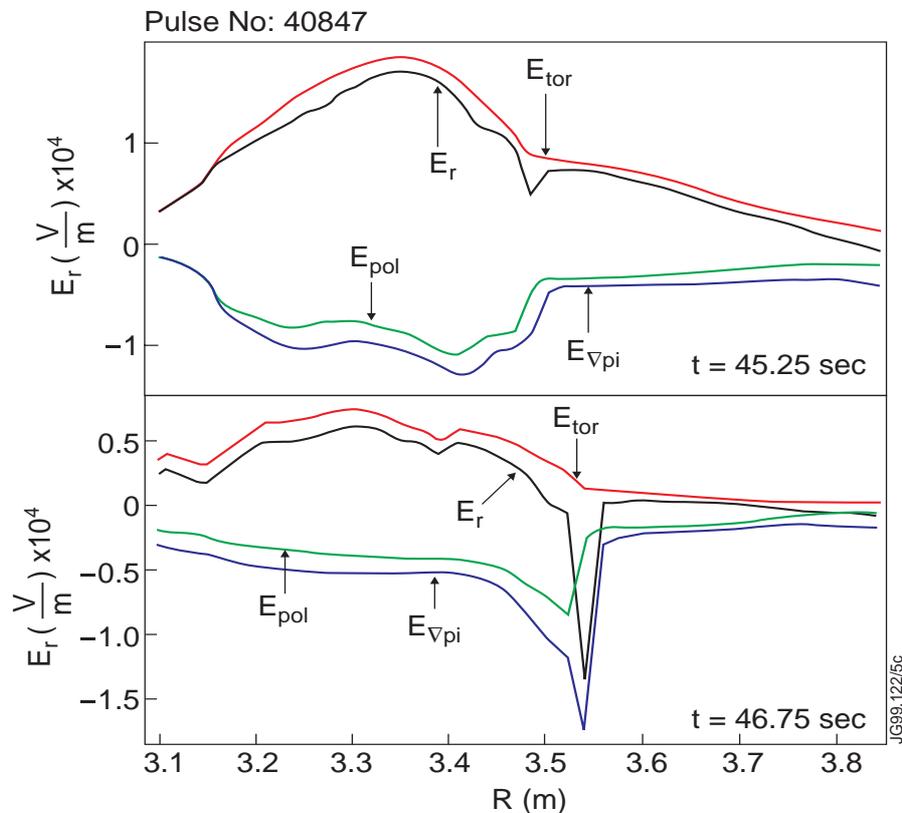
Pulse No: 40847

Figure 5. Radial distribution of the calculated radial electric field at the beginning of plasma heating and during the later phase.

4. Summary

The self-consistent predictive modelling of JET ELMy H-mode and Optimised Shear plasmas, which include simulation of plasma rotation, is presented. The analysis revealed possible reasons for experimentally observed partial degradation even complete collapse of the ITB. The relative importance of the different mechanisms in the ITB formation has been evaluated.

5. Acknowledgement

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