Transport Analysis of the Giant ELMs in JET

V.V.Parail, B. Balet, P. Bak, J.G. Cordey, A. Cherubini, M.Erba, N. Delijanakis, M.F.F. Nave, L. Porte, E. Springmann, A.Taroni, G. Vayakis.
JET Joint Undertaking, Abingdon, Oxon, OX14 3EA, United Kingdom.

1. Introduction

The analysis of experimental data shows that typical giant ELMs in JET are triggered by a short MHD event (with $\Delta\tau_{MHD} \le 1ms$) which effectively increases the electron thermal conductivity in the outer part of the plasma column up to a level which is much higher than the corresponding value for L-mode plasmas. This short MHD burst in JET is usually followed by a relatively long (with $\Delta\tau_L \approx (10 \div 30)ms$) phase of strong density fluctuations and enhanced transport, after which the plasma returns to a quiescent H-mode phase. Numerical analysis performed with the predictive transport code JETTO allows us to conclude that the second phase of the ELM can be reproduced using the same plasma transport coefficients as the conventional L-mode phase. Analysis shows also that the time average energy confinement time for the ELMy H-mode plasma is mainly controlled by the L-mode part of the ELMy H-mode and not by its MHD part, in spite of the fact that anomalous transport is much larger during the MHD event.

2. Modelling of the ELMs in JET

Giant ELMs give an interesting example of fast global modification of plasma transport properties in JET. Following the DIII-D definition [1] we will discuss here only type I ELMs which repetition frequency increases with the heating power and which lead to a significant reduction in plasma performance ($\geq$10%).

The characteristic evolution of electron temperature during successive giant ELMs measured by the new 48 channels heterodyne radiometer system is shown in Fig. 1, together with the Dα signal for shot #30592 (Ip = 2.5MA, Bt =2.8T, Pin = 13MW, $<n_e> = 3.0 \cdot 10^{19} p/m^3$) . These measurements, combined with the soft X-ray measurements [2] indicate that JET giant ELMs have a global character- the electron temperature is changed during MHD event not only near the plasma edge but far inside the plasma volume. The characteristic radial extent of T_e drop at the onset of the MHD event increases with ELM amplitude and reaches value of $\Delta R \geq 0.4m$. The characteristic delay time between the onset of the T_e drop near the edge and at mid radius is less than the diagnostics resolution time $\Delta\tau \approx 1ms$ and cannot be explained by the conventional theory of heat pulse propagation. The ELM appears to be triggered by an MHD event, which is accompanied by the excitation of a broad band range of magnetic fluctuations. This short MHD burst is followed by a relatively long (with $\Delta\tau_L \approx (10 \div 30)ms$) phase of enhanced transport, after which the plasma returns to a quiescent H-mode phase. This second part of a giant ELM is accompanied by a broad band of density fluctuations with a spectrum which is similar to those in L-mode plasma. Two successive ELMs are separated by a quiescent H mode phase which duration varies from ELM to ELM. Such a behaviour is similar to that found in DIII-D in the intermediate range of heating power and called compound ELM [1]. Compound ELMs in JET are quite regular when the heating power is well above the threshold of L-H transition.

We performed predictive numerical modelling of typical giant ELMs on JET keeping in mind the experimental observations. The main objective of this modelling were the following. First of all we have checked whether transport coefficients during the second phase of compound ELMs indeed correspond to L-mode confinement. Hence we have tried modelling this phase with the Bohm model previously used for the modelling of the L-mode JET plasma:

$$\chi_e = \alpha_e \frac{c|\nabla(nT_e)|}{eBn} aq^2, \quad \chi_i = \chi_i^{neo} + \alpha_i \frac{c|\nabla(nT_e)|}{eBn} aq^2 \qquad (1)$$

where $\alpha_i{}^L \approx 3\alpha_e{}^L \approx 6 \cdot 10^{-4}$ [3]. Subsequently we have tried to find a transport model which reproduces the MHD events. In order to model this phase we adopt the following expression for the electron thermal diffusivity:

$$\chi_e^{MHD} = \chi_e^L\left(1 + \alpha \cdot \exp\left(1 - {\rho}/{\Delta\rho}\right)\right) \qquad (2)$$

where χ_e^L is an electron thermal diffusivity in L-mode, α is a numerical factor (varying from ELM to ELM, generally $\alpha \leq 10$), ρ is the normalised radial coordinare ($\rho = 1$ at the separatrix) and $\Delta\rho$ is the normalised radial width of the region with enhanced transport (usually $\Delta\rho \leq 0.2$-0.3). We point out that we are not proposing equation (2) as a model for the MHD event: from the use of model (1-2) we will deduce the radial width of the MHD event $\Delta\rho$ and we will be able to evaluate the impact of the MHD event on the global confinement time.

The result of the modelling of one of the giant ELMs of shot #30592 is shown in Figs. 2: as it can be seen, the L-mode phase is necessary in order to obtain good agreement with the data. For this simulation we have used $\alpha = 5$ for the ELM at t=11.82s and $\Delta\rho$=20cm. Similar results have been obtained for the giant ELMs of discharges #33032 and #33648.

From our simulations we can also deduce information on the relative importance of the various phases in determining the global energy confinement time of ELMy H-mode JET plasmas. In order to proceed in this way, we have to define a proper time average of the energy confinement time for ELMy H-mode plasma $\left\langle \tau_E^{th} \right\rangle$:

$$\frac{1}{\left\langle \tau_E^{th} \right\rangle} = \frac{1}{\Sigma \Delta t}\left(\frac{\Delta t_{MHD}}{\tau_E^{MHD}} + \frac{\Delta t_L}{\tau_E^L} + \frac{\Delta t_H}{\tau_E^H} \right) \qquad (3)$$

where τ_E^{MHD} , τ_E^L, and τ_E^H are the computed energy confinement time during MHD , L-mode and H-mode phases of a compound ELM respectively and Δt_{MHD}, Δt_L and Δt_H - the characteristic duration of these phases. For further discussion it is convenient to introduce the enhancement factor $H_\chi \equiv \left\langle \tau_E^{th} \right\rangle / \tau_E^{ITER89-L}$ which shows how much an effective energy confinement time in ELMy H mode exceeds the level of L-mode confinement. The main characteristic of plasma confinement for three successive ELMs for shot #30592, discussed earlier, compound ELMs for shot #33032 and for shot #33648 are listed in Table.

shot	Δt_{MHD} (ms)	$\tau_E^{MHD}(s)$	$\Delta t_L(ms)$	$\tau_E^L(s)$	$\Delta t_H(ms)$	$\tau_E^H(s)$	$\left\langle \tau_E^{th} \right\rangle(s)$	H
#33648	1	0.05	40	0.25	120	1	0.53	2.13
#33032	2	0.04	40	0.41	80	2.3	0.67	1.8
#30592 large	3	0.04	30	0.18	130	1.1	0.45	2.1
#30592 medium	3	0.06	30	0.2	180	1.15	0.6	2.8
#30592 small	2	0.06	20	0.2	70	1.3	0.49	2.3

From this table the relative importance of the various phases of ELMs in determining the time average electron thermal conductivity of ELMy H-mode JET plasma can be deduced. It follows from our analysis that in the case of giant ELMs the L-mode phases is the most important one in determining the global confinement, while the MHD event is less important due to its short duration.

3. Conclusions.

Experimental study and transport analysis of giant ELMs in JET reveales that such ELMs have a composite structure - each of them is triggered by short MHD event which modify electron temperature not only near the plasma edge but also far inside the plasma volume. This short MHD event turns into much longer phase of enhanced transport that can be modelled as an L-mode. A quiescent H-mode phase then follows. Therefore the ELMy H-mode plasma in JET (in cases when type I ELMs are dominant) is a composition of three different phases: short (with $\tau_{MHD} \approx 1 ms$) MHD with transport coefficients much larger that in L-mode plasma, longer (with $\tau_L \approx 10 - 30 ms$) phase of enhanced transport during which transport corresponds to L-mode confinement and finally ELM-free H-mode phase.

The relative importance of each phase depends on the amplitude of the ELM with a general trend that the relative importance of L-mode phase grows with ELM amplitude.

4. Acknowledgements

The authors would like to acknowledge fruitful discussions with R. Gianella, T. Jones, J. Lingertat, P. Lomas, P. Thomas, K. Thomsen and Task Force H and D for providing the experimental information.

References

[1] Schissel, D.P, et al., Proc. 19th European Conference on Controlled Fusion and Plasma Physics, Innsbruck, Austria, 1992, Vol. I, p. 235.

[2] M.F.F. Nave et al., Proc. 1994 International Conference on Plasma Physics, Foz do Iguaci, Parana, Brazil, 1994, also JET-P(95), 03.

[3] Taroni, A., Erba, M., Springmann, E. and Tibone, F., Plasma Physics and Contr. Fusion, **36**, (1994), 1629.

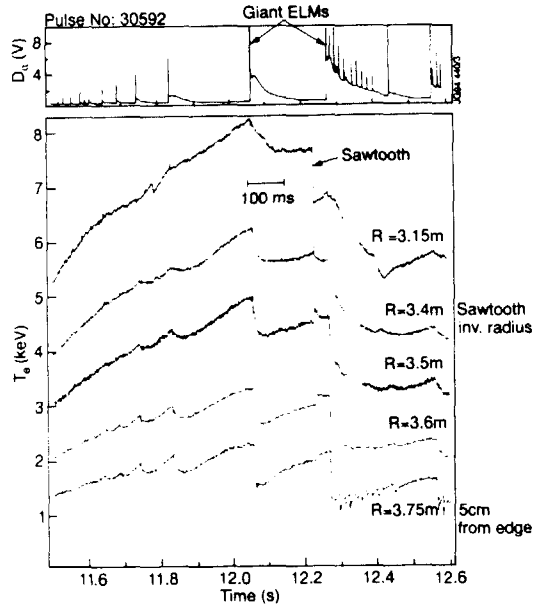

Fig.1. Time evolution of the $D_\alpha$signal and of the electron temperature at different radial positions during giant ELMs in shot #30592.

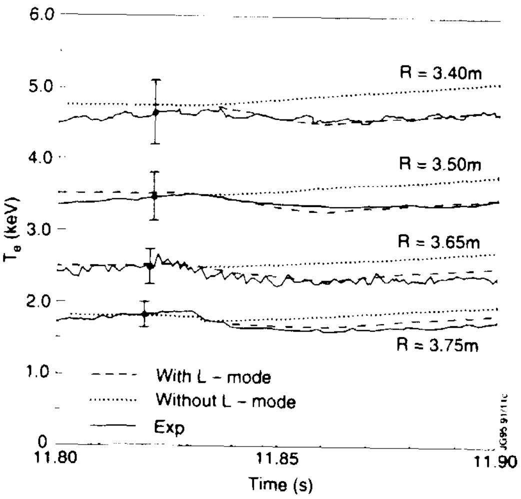

Fig. 2. Time evolution of the experimental (solid line) and simulated (dotted and dashed lines) at different radial positions during giant ELM of #30592 at t=11.83 s. The dotted line represent the result of modelling without a phase of L-mode-like transport after the initial MHD phase.