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Modeling of L to H-mode transition in JET

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Introduction

Recently, the linear transport model, allowing for the low (L) to the high confinement mode (H-mode) transition and tested previously in RITM transport code [1], has been introduced to the 1.5D transport code JETTO [2]. The model accounts for drift instabilities of different nature, e.g. ion temperature gradient (ITG) and trapped electron (TE) modes, which are dominating the transport in the plasma core, as well for modes driven by collisions and current perturbations, like drift resistive ballooning (DRB) and drift Alfven (DA) instabilities, which are particularly important at the plasma edge under the L-mode conditions. These edge modes are stabilized by increasing pressure gradient and decreasing collisionality. Local analysis shows that, the reduction of the turbulent transport driven by edge instabilities occurs, if the total heating power exceeds some critical level, P_{th} [3], which is interpreted as the H-mode power threshold. Present paper focuses on the validation of the model predictions against experimental results obtained in JET tokamak [4]. Comparison is done for a number of JET discharges, in which the line averaged density and the magnetic field have been varied. Both computed and experimental results were also compared to the inter-machine scaling law [5].

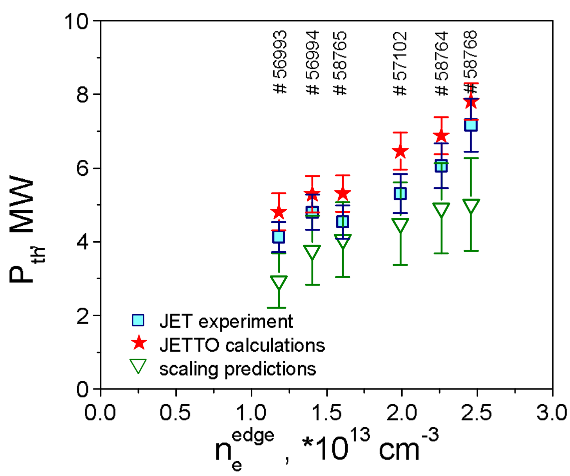

Fig.1 Comparison of the L-H power threshold computed with the JETTO code to the values obtained in experiment and predicted by the inter-machine scaling, for the set of discharges with various densities.

The comparison of the model predictions to results of non-linear computations is outside of the scope of the present paper. Nevertheless, it should be mentioned that, so far, nonlinear computations done for similar plasma conditions do not reproduce this sudden reduction of the turbulent transport with increasing pressure gradient. Reasons for this disagreement are not clear at the moment; the understanding requires further benchmarking activity.

Density and magnetic field scans for P_{th}

The inter-machine scaling derived from data base, which includes results from several divertor tokamaks, defines the critical power for the L-H transition in MW: $P_{th} = 0.042\,\bar{n}_e^{0.64}\,B^{0.78}\,S^{0.94}$, where $\bar{n}_e$ is the line averaged electron density in $10^{20}m^{-3}$, S the plasma surface area in m^2, and B the toroidal magnetic field in T [5]. Thus, modeling of the L to H-mode transition with the JETTO code has been performed for two series of JET discharges. In the first series the edge density has been varied at the fixed magnetic field and plasma current and in the second one the variation of the magnetic field at the fixed edge safety factor has been done. For all of shots chosen for the analysis, the power scan with the step of 0.5 MW has been performed in order to determine the power threshold for the L-H transition. This was done by the scaling of heat deposition profiles obtained from the experiment. It is also important to note that, the model settings were chosen once, by fitting profiles of the shot #58764, and were kept fixed through all of computations presented in the paper.

The transport modeling requires the knowledge of boundary conditions, e.g. densities, temperatures, neutral particle flux measured at the last closed magnetic surface (LCMS). Moreover, the L to H-mode transition is the edge phenomenon and can be extremely sensitive to the choice of boundary quantities [3,6]. Profiles of edge parameters measured in experiment are, usually, very noisy, that imposes a large uncertainty to modeling results. Also, some of required quantities are not measured at all. Thus, discharges selected for the modeling were first analyzed with 2-D transport package EDGE2d/NIMBUS [7] in order to calibrate edge profiles on physics-based model. The magnetic geometry, neutral puff and energy flux to the SOL have been taken from the experiment. The heat and particle transport coefficients have been provided by JETTO computations and assumed constant over the SOL region.

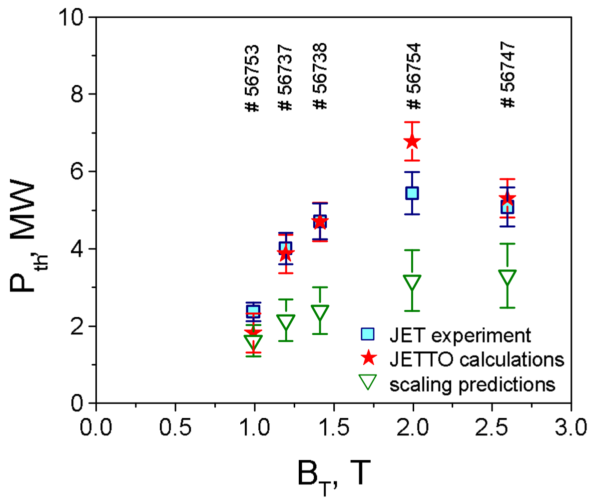

Fig.2 Comparison of the L-H power threshold computed with the JETTO code to the values obtained in experiment and predicted by the inter-machine scaling, for the set of discharges with various magnetic field.

Figure 1 compares the variation of the L-H power threshold with the edge density, obtained from JET experiments, computed with the JETTO code and predicted by the inter-machine scaling law. The transport model adjusted for one particular discharge predicts the L-H power threshold in good agreement with experimental observations for the whole density range. All three sequences of points coincide within error bars; except for the highest density case, where the value predicted by the scaling law is about 30% lower than experimental and computed values. The larger difference at the higher densities is most probably due to different $P_{th}(n_e)$ dependence found in JET with different divertor configurations [8] . This is not taken into account by the general scaling constructed on the old JET data obtained with substantially different divertor configuration.

Computations done for the sequence of discharges with different values of the magnetic field are shown in fig.2. It is important to note that, keeping the model setting fixed, the switch to substantially different plasma conditions compared to fig.1 did not break the agreement between experimental and numerical results. The experimental variation of the power threshold for the L-H transition is well reproduced by the modelling. Nonetheless, there is a substantial difference to the value of the critical power predicted by the inter-machine scaling under all conditions, although trends between different curves agree. The explanation is similar to what was given for the fig.1. Discharges analysed in fig.2 have substantially different magnetic configurations with different X-point positions. The latter has a strong impact on the power threshold [8], which is omitted by the general scaling.

Minimum of $P_{th}(n_e)$ dependence

The JETTO code has been also applied to investigate the causes of deviations from multi-machine scaling observed in JET tokamak at low density conditions [4]. It has already been demonstrated in computations with the RITM code for conditions of TEXTOR tokamak [3] that, the strong convective heat losses driven by particle flux is the key factor for this deviation. The deep penetration of neutrals into confined plasma leads to the substantial increase on the heat losses due to the charge particle convection. This results in the lower temperature and its gradient. Thus, higher power is needed to reach critical pressure gradient for the stabilization of the turbulent transport at the edge.

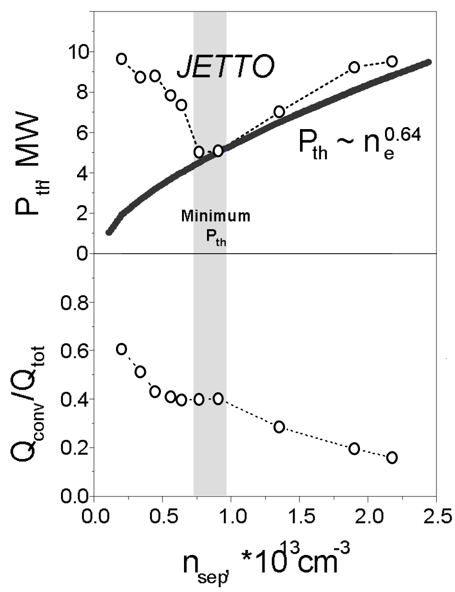

Fig.3 L-H power threshold computed with the JETTO code for low density conditions: the minimum of $P_{th}(n_e)$ dependence correspond to the critical fraction of convective heat losses at the edge, Q_{conv}/Q_{tot}~0.4.

Figure 3 presents the threshold power for the L-H transition and the fraction of convective losses in the total heat flux at the edge as a function of the density at the separatrix obtained in JETTO computations. For densities above 0.7-0.8*$10^{13}cm^{-3}$, computations reproduce the $P_{th}(n_e)$ dependence proposed by the scaling law, P_{th}~$n_e^{0.64}$. For lower densities, computations reproduce the minimum of $P_{th}(n_e)$ dependence in agreement with JET experiment [4]. Densities, at which the minimum is achieved, roughly correspond to experimentally measured densities at the pedestal top of ~ 1.1-1.3*$10^{13}cm^{-3}$ [4]. The fraction of convective losses increases with the density decrease due to weaker attenuation of the neutral flux released by walls in the divertor region and SOL. This provides an explanation for the higher power threshold at low densities. The critical fraction, at which the minimum of $P_{th}(n_e)$ dependence is observed, is about 0.4. This roughly corresponds to the previously obtained 0.5 for TEXTOR conditions [3]. Nonetheless, disagreement with the scaling at low density it is not a contradiction, since the scaling was constructed using the data from the high density discharges only [5], and thus, does not reproduce the power threshold at low densities. Moreover, the criteria used to select data for scaling construction, $l_n<0.1\kappa a$, is in line with our conclusion on the crucial role of neutrals in determining the threshold power for L-H transition at low densities. Here l_n is the neutral penetration length, κ is the elongation and a is the minor radius.

Summary

The RITM transport model allowing for the self-consistent modeling of plasmas with the edge transport barrier has been introduced into the 1.5-D transport code JETTO. The model was calibrated on experimental plasma profiles for the L-mode conditions, when free normalization constants used in the model have been tuned and fixed. Computations done for sequences of JET discharges, with different values of the plasma density and the toroidal magnetic field, show the reasonable agreement between the modeling and experimental results. At the same time, the inter-machine scaling tends to under predict the L-H power threshold in selected discharges. This might be explained by the influence of the divertor configuration on the power threshold, which is not included in the general scaling. The minimum of $P_{th}(n_e)$ dependence at low density can be explained by the deep penetration of neutrals into confined plasma, which leads to higher convective energy losses, and, thus, to the increase of P_{th}. The critical fraction of convective energy losses, corresponding to the minimum of $P_{th}(n_e)$ dependence is about 0.4-0.5 of the total heat losses.

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