LH-transition dynamics in the presence of GAM and pellet-injection

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Improved confinement mode in a toroidal fusion device, or H-mode, is a necessary operational regime for thermonuclear devices. H-mode is characterized with the presence of peripheral transport barrier – an area in which anomalous (or turbulent) transport is suppressed. Turbulence suppression is connected with the existence of strong inhomogeneity (shear) of radial electric field E_r. Thus if it is possible to create strong enough inhomogeneous electric field, it is possible to initiate the transition to improved confinement mode (LH-transition). However, there could be other factors responsible for LH-transition initiation possibility.

In the present paper two methods of creating strong E_r shear are discussed. Geodesic acoustic mode (GAM) creates strong inhomogeneity of radial electric field and transverse rotation and thus affects anomalous transport through control of turbulence level [1]. Cryogenic fuel pellet injection creates localized perturbation of particle source, which leads to density gradient and ion temperature gradient perturbation, which both build up inhomogeneous radial electric field [2]: $E_r = \frac{T_i}{e}\left[\frac{\partial \ln n}{\partial r} + k_T \frac{\partial \ln T_i}{\partial r}\right]$.

In TUMAN-3M (a=0.22 m, R=0.55 m) and FT-2 (a=0.08 m, R=0.55 m) tokamaks GAM activity was observed with different diagnostics and carefully studied. In TUMAN-3M GAM develops in the vicinity of LCFS and could exceed the value of mean radial electric field [3, 4]; in FT-2 tokamak GAM exists in the vast area close to the half of minor radius [5]. GAM-induced electric field value in FT-2 deuterium discharges also exceeds mean E_r, but is also significantly higher than in TUMAN-3M (up to 15 kV/m in FT-2 vs. 4.5 kV/m in TUMAN-3M). However in TUMAN-3M there is observed LH-transition after bursts of GAM, and in FT-2 tokamak LH-transition is absent.

Similar situation is being observed in TUMAN-3M tokamak in pellet-injection scenarios – with the similar perturbation of density and temperature gradients and thus the similar radial electric field perturbation, pellet (if evaporated in peripheral plasma and followed by a gas cloud from deconstructed part of that pellet) could either lead to

LH-transition, or (if evaporated deeper in plasma) cause only a transient confinement improvement.

To understand the mechanism responsible for confinement improvement and H-mode initiation, the model of particle density and ion temperature evolution was used. In the model the effect of turbulence suppression was included via the diffusion coefficient dependence on E_r shear in the form as in [6]. This form of diffusion coefficient requires the information about turbulence growth increment; the value of that increment was obtained form ELMFIRE code gyrokinetic simulations [7]. Also ELMFIRE proved the fast (relatively to GAM frequencies and τ_p-scale processes in plasma) reaction of diffusion coefficient on the modulation of E_r shear.

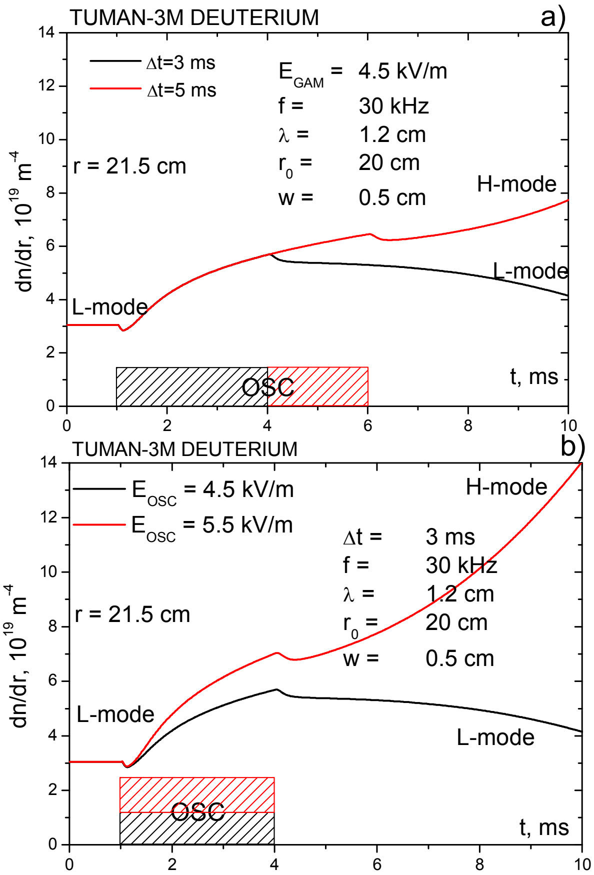

Fig.1 TUMAN-3M model: LH-transition initiation by GAM with duration (a) and amplitude (b) exceeding threshold values

In the scenarios with GAM experimental low-density discharge of TUMAN-3M [3,4] and deuterium 19 kA discharge of FT-2 [5] were modelled. For both tokamaks, plasma parameters profiles were either measured of obtained from ASTRA code. GAM parameters were obtained from experiments [3, 4, 5] and ELMFIRE simulation [7]; GAM electric field was taken in the form of time- and space-localized travelling wave. Modelling of TUMAN-3M and FT-2 scenarios yielded results, consistent with experimental. In TUMAN-3M case LH-transition occurs if amplitude or duration of GAM burst exceeds certain thresholds (fig. 1). These thresholds depend on all the plasma parameters – ion temperature primarily – and are more thoroughly discussed in [8]. In FT-2 case despite the higher E_r shear value LH-transition was not observed even with twofold increased experimental GAM amplitude and duration (fig. 2).

In the scenarios with pellet-injection in TUMAN-3M tokamak plasma parameters were taken close to experimental, area of pellet source and substance deposition was

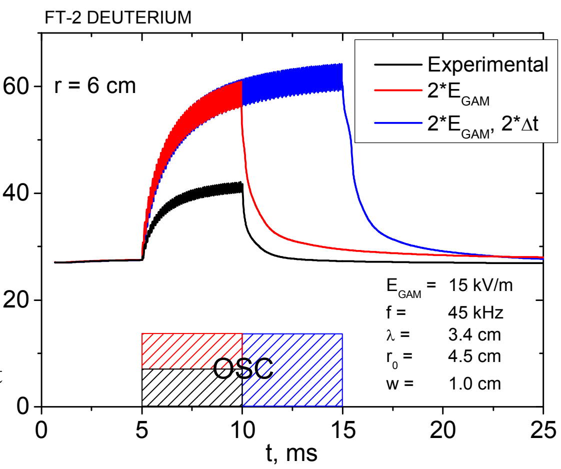

Fig.2 FT-2 model: LH-transition does not occur even with very strong E_r perturbation

obtained from the evaporation curve, observed with D_α emission detectors; diagnostics geometry makes it possible to restore temporal and spatial distribution of pellet source. Gas cloud from the disintegrated part of the pellet was included in the model as an increase of cold neutrals source from plasma periphery; charge exchange and adiabatic cooling processes were considered in the ion temperature evolution calculation. In case of peripheral evaporation (maximum at r = 19 cm) and gas cloud LH-transition occurs (fig. 3a), and it is also observed that the presence of increased particle source caused by the gas cloud plays crucial role in transition initiation; without it E_r perturbation alone is not enough for the transition. In case of deeper evaporation (maximum at r = 17 cm) and only solid pellet there is observed confinement improvement which quickly (less than 1 ms) decays to initial state (fig. 3b). Though amplitude of density gradient and diffusion perturbation is close to experimental, duration of decay is significantly shorter than in experiment. The cause of this difference is still unclear and we hope that further improvements to the model could make it more consistent with the experiment.

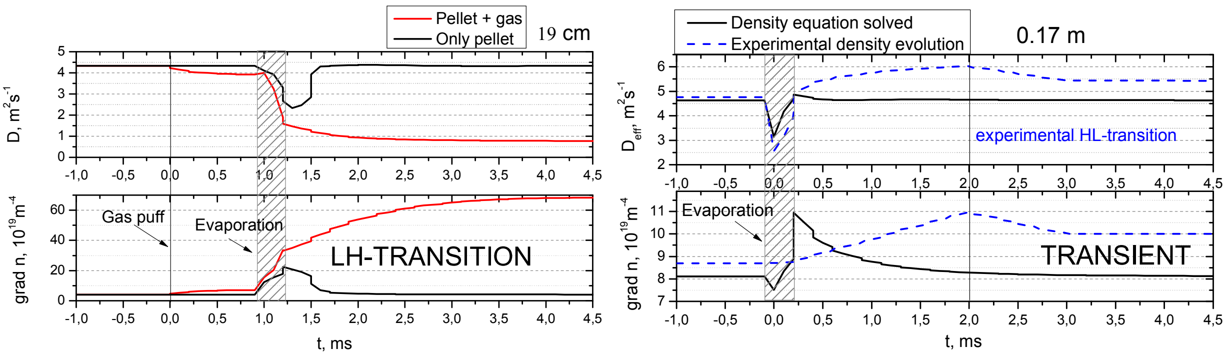

Fig.3 TUMAN-3M pellet injection model with LH-transition (a) and transient confinement improvement (b)

As it was possible to see from pellet-injection modeling, particle source plays significant role in the possibility of LH-transition initiation. This result is quite consistent with the modern theoretical views on the existence of bifurcation in the transport equations solution, which describes two confinement modes [9]. To apply this analysis to the modeled cases, is necessary to integrate stationary diffusion equation, which yields: $-D_{eff}(\nabla n(r))\cdot\nabla n(r) = S_{\text{int}}(r)$. LHS is particle flux dependent on density gradient, RHS is integral particle source. With the diffusion coefficient dependence on density gradient the form of $\Gamma(\nabla n)$ is non-linear (so called N-curve) with three parts – two with positive derivative correspond to stable solutions for L- and H-mode, and non-stable with negative derivative, which makes possible the bifurcation of particle flux value. Intersections of N-curve and horizontal line at level of stationary integral source determine the existence of confinement modes. Fig. 4 a) and b) show the N-curves for GAM initiated transition in TUMAN-3M and FT-2, and fig. 4 c) and d) correspond to the pellet-injection.

Estimation based on experimental parameters shows that GAM and pellet+gas cloud scenarios in TUMAN-3M have integral particle source in the area of three intersections, thus strong enough E_r shear perturbation could switch the confinement regime; FT-2 GAM and TUMAN-3M deep solid pellet scenarios have too low integral particle source for present flux value, thus only stationary L-mode is possible.

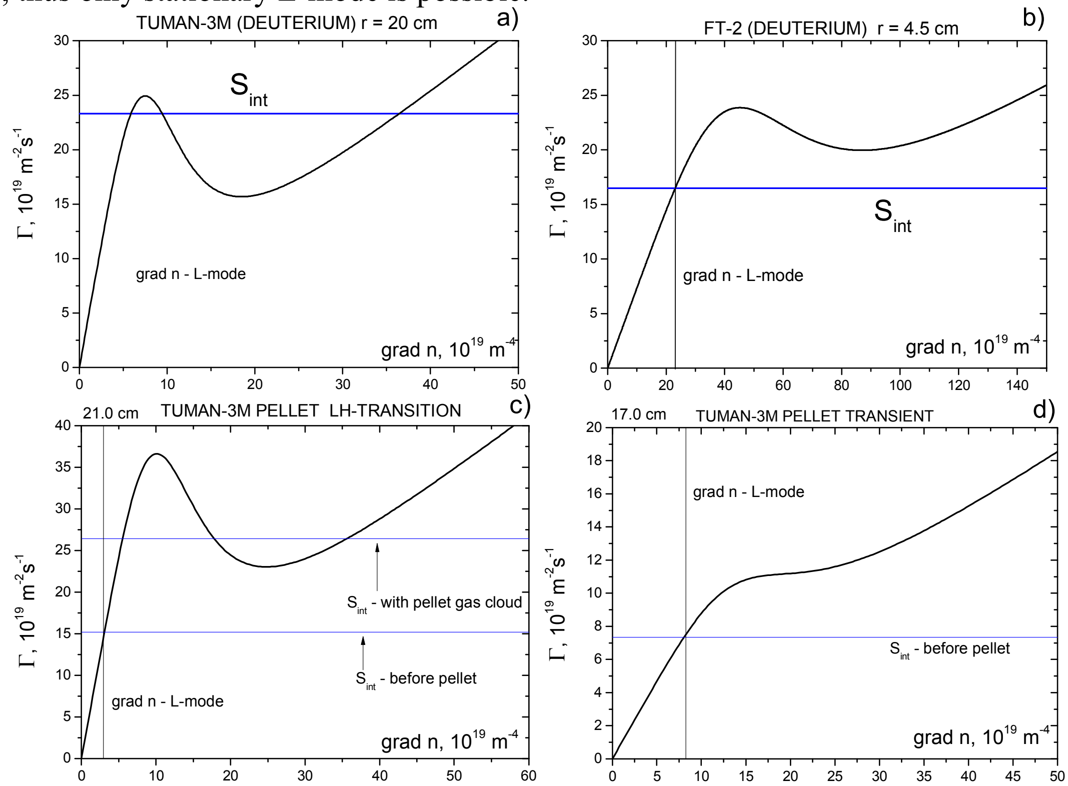

Fig.4 N-curves for GAM scenarios in TUMAN-3M (a) and FT-2 (b) and pellet scenarios with (c) and without (d) gas cloud from deconstructed part of the pellet.

To summarize with, the model based on experimental data and ELMFIRE gyrokinetic simulation which calculates the modulation of plasma confinement with possibility to define the presence or absence of LH-transition, yields results qualitatively consistent with experimentally observed and could prove turbulence parameters obtained from ELMFIRE gyrokinetic code. Modeling results along with LH-transition theory [9] indicate that high E_r shear alone may not be enough for LH-transition initiation; source value plays significant role in defining possibility of H-mode existence.

Authors would like to acknowledge RFBR for partial financial support (grants 16-02-00580 - A.D. Gurchenko and 15-02-03766 - E.Z. Gusakov) and CSC – IT Center for Science, Finland, for computational resources.

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