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Modeling of L–H/H–L Transition in TSC Simulation Using JT-60U Experimental Data

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A simulation model with TSC code was developed to describe the plasma behavior during L-H and H-L transition phase, which was mainly aimed at prediction of the ITER plasma behavior during current ramp–up/down and flat top phase. The model was compared with existing JT-60U experimental data. From the engineering viewpoint of coil and power supply design, estimation of plasma resistivity is an important issue, especially in H-L transition during ITER current ramp-down phase. The determination of plasma resistivity strongly depends on transport model, particle and heat sources. However, the estimation of particle source includes a lot of complicated physics related to fueling, divertor pumping, charge exchange penetration, wall retention and so on.

Recently, we implemented a particle source model including these physics to the TSC code as shown in figure 1. To simplify calculation, spatial distribution of neutral is represented by two values, the edge neutral density n_E^o and the divertor neutral density n_D^o. The out–flux from the plasma F_p, which is flowing into the divertor region, is calculated by

$$F_p = -\frac{d}{dt}\int n_p dV_p + S_{NB} + S_i \ ,$$

where S_{NB} and S_i are particle fluxes from NB and ionization respectively. The particle flux from the divertor region to the edge region F_n is modeled on an assumption. In this study, we assumed that n_E^o is just proportional to n_D^o, that is

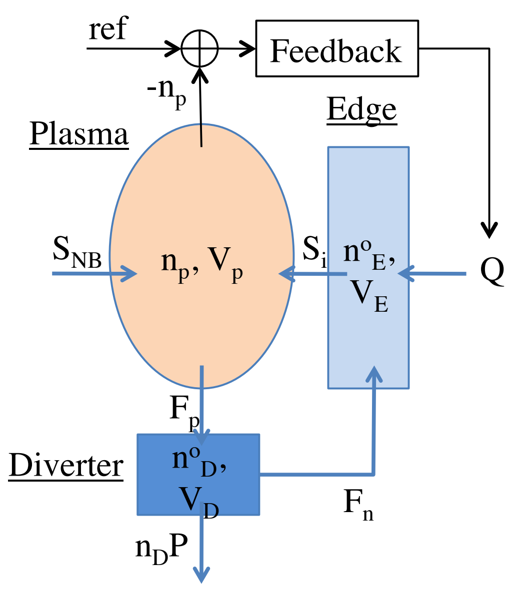

Figure 1: Neutral model

$$n_E^o = C_{DE} n_D^o \ ,$$

instead of specifying F_n. Here C_{DE} is a model parameter which is adjusted by experimental data. We confirmed that this assumption held reasonably well by comparing with more precise model in which F_n was described by a conductance between two regions, $F_n = (V/\tau)(n_D^o - n_E^o)$.

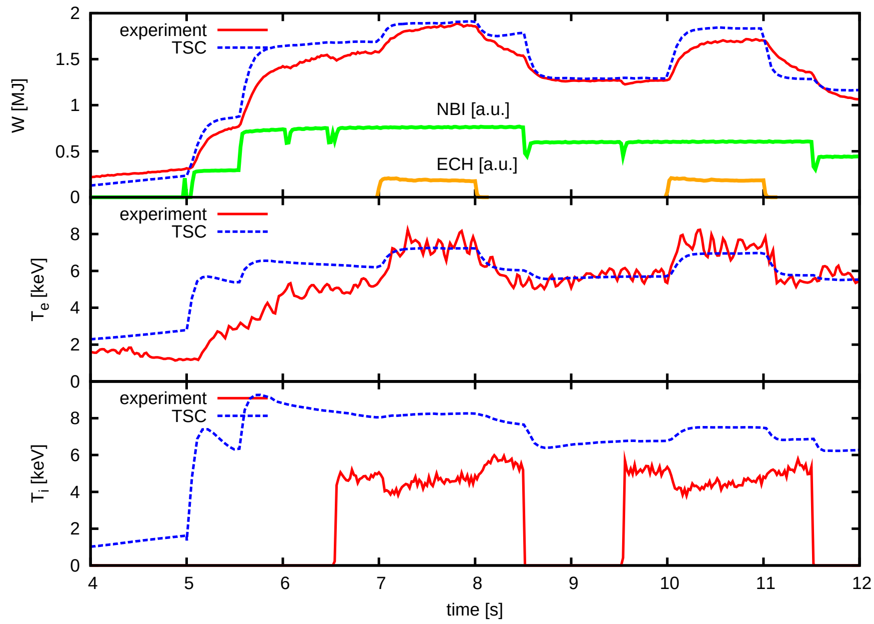

Figure 2: Stored energy (top), central electron temperature (middle) and central ion temperature (bottom). Only limited time duration ($6.5 < t < 8.5$ and $9.5 < t < 11.5$) is assigned for ion temperature measurement.

To be accurate in predicting density profile during L–H or H–L transition, it is important to calculate ionization source profile. In our model, penetration of Franck–Condon neutrals due to charge exchange up to fifth generation determines the ionization profile with the edge boundary density n_E^o. In actual plasmas, the most part of ionization takes place in a scrape–off layer (SOL) and the neutral flux from the edge region to the main plasma becomes much smaller. In our present model, this screening effect of SOL is simply modeled by putting S_i at 1/100 the calculated value.

This model is compared with a JT-60U shot #049556, in which an H-mode plasma is sustained with NBI and ECH without gas puffing. Because, in this shot, L-H and H-L transitions are triggered by ECH maintaining NBI power constant, it is possible to analyze the behavior of bulk neutrals excluding the influence of neutrals arising from NBI. In figure 2, a TSC simulation is compared with the experimental shot. In usual TSC runs, gas feeding rate is feedback controlled so that the average density keep track of the experimental value as shown in figure 1 while, in this comparative study, feedback is switched off at 5 sec. The TSC code reproduced history of stored energy and central electron temperature well. TSC could also reproduce ion temperature in the edge, but could not account the temporal change due to ECH heating at the center as shown in the bottom panel of figure 2. This difference may be resolved in a future

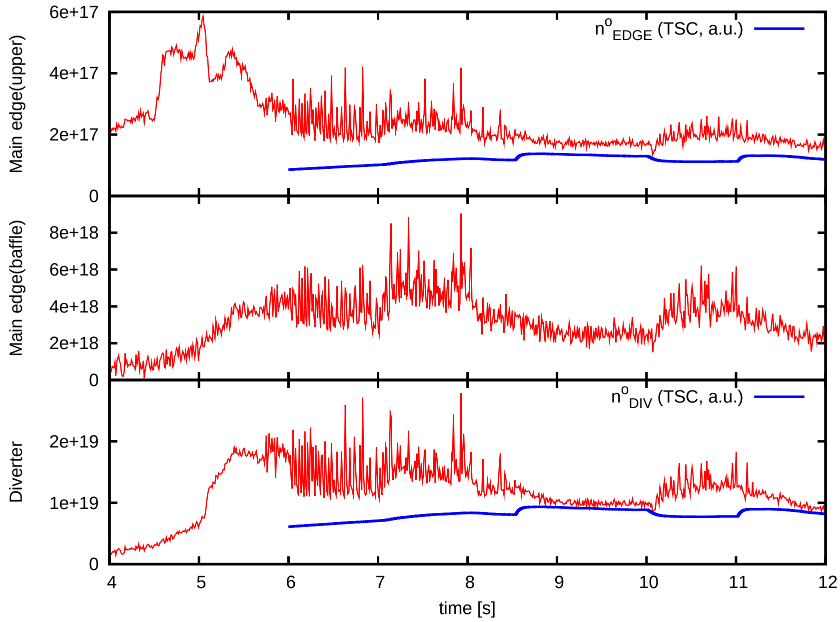

Figure 3: D_α signal. Temporal change in calculated neutral densities in TSC are also shown for comparison.

study. Note that in the figure, only limited time duration ($6.5 < t < 8.5$ and $9.5 < t < 11.5$) is assigned for measurement of ion temperature.

Experimentally observed D_α signal reflects neutral density and can be used to infer relative change in neutral density. In figure 3, D_α emission from different regions of the same discharge are shown. We consider the signal from the top edge of the plasma (top figure) as correspondent to the edge neutral density n_E^o, and the signal from the divertor (bottom figure) to n_D^o in TSC simulation. From intensity ratio of the D_α from the top and from the divertor, one of the model parameters C_{DE} can be deduced as $C_{DE} = n_D^o/n_E^o = 1\times10^{-2}$.

Behavior of electron density and neutral density are shown in figure 4. From the experimental D_α signal, it is inferred that the first L–H transition took place at 5.6 sec with a neutral beam injection and stayed in H–mode until the NBI power stepped down. After the discharge once went back to L–mode, the second L–H transition took place at 10 sec with ECH injection keeping a constant NBI power. To model L–H transitions, we change the width of edge transport barrier from $\Delta\rho = 0.04$ to 0.06 before and after transitions and vise versa to model H–L transitions. Simulations are carried out with different parameters, $C_{DE} = 1\times10^{-2}$, 2×10^{-3} and 5×10^{-4}. In the case of $C_{DE} = 1\times10^{-2}$, sharp rise or drop in averaged density and correspondingly negative or positive spikes in neutral density are observed coincidently with the L–H or H–L transitions. However, these rapid changes in plasma and neutral densities are unrecognizable in

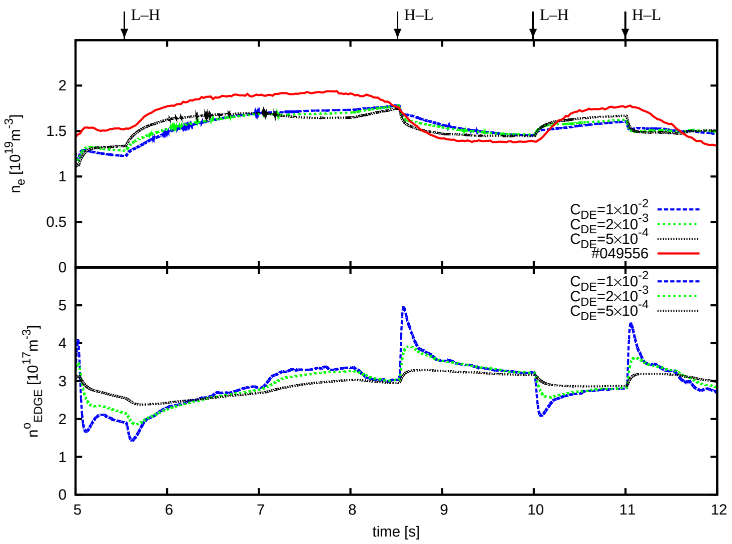

Figure 4: Line averaged density (top) and edge neutral density (bottom).

the experimental data (figure 3 and 4).

One of the cause of this different behavior is considered as follows; In a real discharge, there are a lot of particles in ionized state, not only in atomic or molecular state in the divertor region. Therefore the density ratio n^o_D/n^o_E including ionized gas is much greater than the ratio inferred from the experimental D_α ratio so that the fluxes from the plasma due to transitions are absorbed completely. To see this effect, TSC simulations with changing C_{DE} are done as shown in figure 4. In these runs, pumping speed is changed accordingly with C_{DE} to keep pumping flux $n^o_D P$ constant. When increasing the density ratio n^o_D/n^o_E (reducing C_{DE}), the spikes in neutral density become small and almost disappear at $C_{DE} = 5\times10^{-4}$.

Finally, temporal change in calculated neutral densities ($C_{DE} = 5\times10^{-4}$) are compared with that in D_α signal in figure 3. It is obvious that both calculated neutral density and D_α signal show step function–like responses to the H–L and L–H transitions. However, the direction of response is opposite; in TSC, neutral densities in both region are low in H–mode and high in L–mode unlike experimental D_α. Because, in our model, a pumping flux $n^o_D P$ is much smaller than the neutral flux from divertor to edge region F_n, a sum of plasma particle and neutral particle numbers is almost unchanged. The neutral density, therefore, increases when plasma particles are spilled out due to H–L transition. To resolve this difference, probably we need to include a divertor and SOL plasmas in our model in a further study.

In conclusion, the behavior of neutral becomes close to experimental observations when the effect of divertor plasma is taken into account. A further modeling is required to extend this study to the scenario development of ITER.