STUDIES OF T-10 DISCHARGE QUENCH DURING INJECTION OF IMPURITY PELLETS

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1. Introduction

A mitigation of the discharge disruption in large tokamaks by means of pellet injection is one of the key tasks of these machines. There are two different approaches. First, there is injection of large pellets from either light impurities or deuterium [1,2]. The potential problem of this technique is a fairly large increase of the plasma density after pellet injection, which may lead to a density limit disruption. Injection of pellets made from a high Z noble gas [3] could significantly decrease the required amount of ablatant but may lead to runaways [2]. Indications of runaways generation were observed in the first killer pellet experiments using large high Z pellets [4,5,6,7]. We notice that no runaways were observed after large Ne pellet injections into Asdex Upgrade plasmas [8]. An impressive technique to avoid the generation of runaways on JT-60U by means of exciting large magnetic perturbations was reported in Ref. [6]. The 0-D considerations of the ITER plasma quench due to pellet injection made in Ref. [3] have been improved by a 1D approach in Ref. [2,11]. These predictions should be confirmed by means of comparison of their predictions for the contemporary killer pellet experiments. The first results of such simulations performed for the plasma quench experiments with KCl pellet injections into T-10 plasma [4] are presented in this report.

2. 1D transport model

The following set of 1D equations for the electron (1) and impurity (2) density, thermal energy balance (3) and a Maxwell equation for the toroidal electric field E (4) was solved numerically:

$$\frac{\partial n}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(r\Gamma) = \frac{\partial (n_{imp} \cdot Z_{imp})}{\partial t} \tag{1}$$

$$\frac{\partial n_{imp}}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}\left(r\Gamma_{imp}\right) = 0 \tag{2}$$

$$\frac{3}{2}\frac{\partial nT}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}\left(r\left[q + \frac{5}{2}\Gamma T\right]\right) - \frac{\Gamma}{n}\frac{\partial nT}{\partial r} = n\left(Q_{oh} + Q_{ec} - Q_{imp} - Q_{br}\right) \tag{3}$$

$$\frac{\partial j}{\partial t} = \frac{c^2}{4\pi}\frac{1}{r}\frac{\partial}{\partial r} r \frac{\partial E}{\partial r} \tag{4}$$

Here, $n = n_D + Z_{imp} \cdot n_{imp}$ is the electron density; $\Gamma = -D\frac{\partial n}{\partial r} + nv_p$,

$\Gamma_{imp} = -D\frac{\partial n_{imp}}{\partial r} + n_{imp} v_p$, $q = -\chi\frac{\partial T}{\partial r}$ are particle, impurity and heat fluxes; Q_{br}, Q_{oh}, Q_{ec} are bremsstrahlung losses, Ohmic and ECR heating. For the impurity line radiation Q_{imp} and the averaged charge of impurity ions Z_{imp}, the coronal equilibrium model [9] was used. The Alcator-like scaling for the transport coefficients $\chi=2\cdot10^{17}/n_e$ [cm^2/s], $D=\chi/2$ was chosen. The current density $j=\sigma E$ was calculated using the Spitzer conductivity law.

3. Results of simulations and discussion

The KCl pellet injection into T-10 shot #62812 (See Ref. [4]) was simulated. The radiation source was created by the KCl pellet of 0.4 mm size and 150 m/sec velocity. The total amount of $N_{imp} \approx 4.5\cdot10^{17}$deposited atoms of potassium and chlorine was evaluated. Plasma parameters before the pellet injection were as follows: plasma current I_p = 250 kA, toroidal field B_t = 2.5 T, limiter radius a_L = 0.3 m, central electron temperature $T_e(0)$ = 1150 eV. Steady state electron density and temperature profiles before pellet injection were simulated using Eq. (1-4) to reproduce those measured by means of the microwave interferometer and the SXR amplitude analyser. The results of these simulations are shown in Fig.1a, c.

The pellet deposition was calculated using its ablation rate as it is described in Ref. [10] using a wide view photodetector [4]. Profiles of perturbations of plasma parameters after pellet injection (dotted lines in Fig. 1) were evaluated using this pellet deposition. These profiles were used as initial conditions for further simulations of the plasma behaviour. The pellet ablation time was assumed to be fairly smaller compared to the quench time. The transport coefficients were fixed to those obtained for the steady state regime.

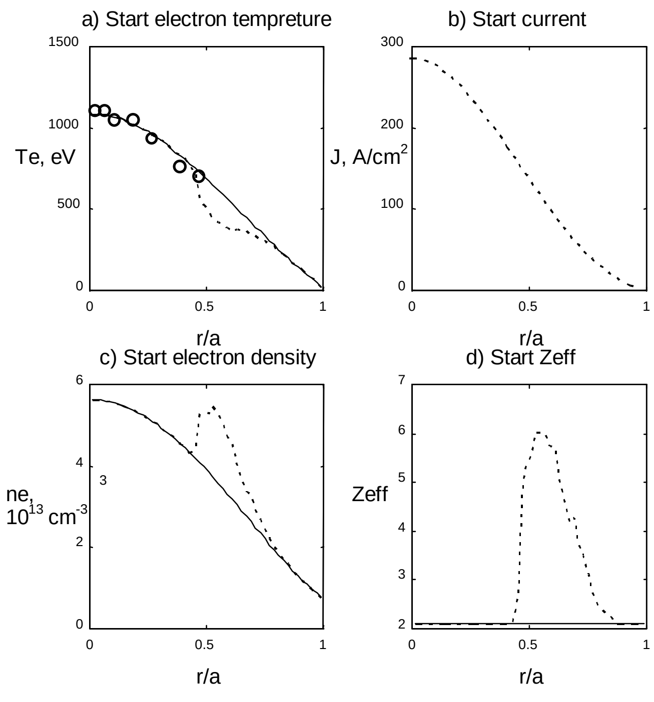

Fig. 1. Initial conditions for simulations of plasma behaviour in shot #61812. Profiles before pellet injections are shown by solid lines, perturbed plasma parameters after pellet injection - dotted curves, circles at Fig. 2a are SXR data of T_e.

Changes of the line-averaged densities for five vertical chords are shown in Fig. 2. Reasonable agreement between experimental and simulated data was found. It is also seen that the

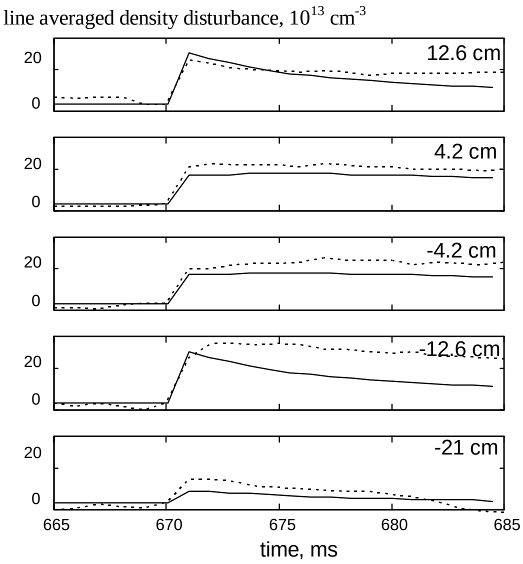

Fig. 2. The line averaged electron density evolution after KCl injection in shot #61812. Dotted lines- experiment, solid lines – simulations. Positions of chords are shown in upper right corner of plots.

measured values for internal chords are higher than those measured for the external ones. This can be explained by a slight plasma shifting (1-2 cm) after pellet injection toward the high magnetic field side as described in Ref. [4]. This plasma shift was not taken into account in our simulations.

Temporal behaviour of the electron temperature measured using four ECE detectors is shown in Fig. 3. We see that the temperature evolution on the periphery channels (15.9 and 20.0 cm of minor radii) can be reasonably simulated up to 30 ms after pellet injection when a burst of MHD plasma activity occurred as described in Ref. [4].

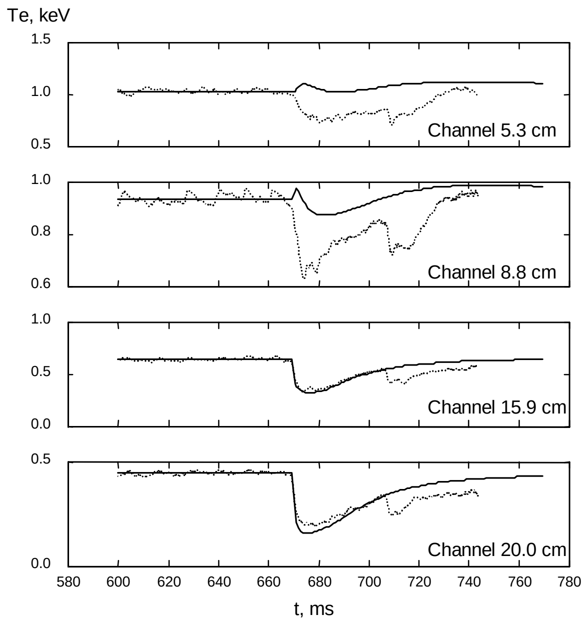

Fig. 3. The electron temperature evolution after KCl pellet injection into shot #61812. The experimental EC diagnostic data are shown by dotted curves, simulated ones - solid curves.

To reproduce these temperature evolutions, together with a temporal evolution of the plasma current and loop voltage after pellet injection, we simulated the operation of the T-10 feed-back system which keeps the total plasma current constant.

The evolutions of internal ECE channels (5.3 and 8.8 cm) demonstrate quite a different behaviour compared with those observed experimentally. In simulations, even a slight increase of the core temperature was observed instead of the experimental drop. It was found that this phenomenon was caused by a particle flux (third term in Eq.(3)) towards the plasma centre initiated by the pellet injection. The following parameters of simulations were varied to fit experimental observations of the core temperature behaviour: ratio of transport coefficients D/χ~0.1-10; amount of ablated atoms N_{calc}/N_{imp}~1-1.5, plasma shift of (1-5) cm during 2-5 ms after injection. Unfortunately, all these manipulations did not allowed us to describe the temporal evolution of the core electron temperature.

One possible mechanism for such an observed phenomenon could be associated with a non-local response of thermal transport on perturbations like discussed in experiments on either edge cooling on JET [12] or pellet ablation within sawteeth inversion radius on RTP [13].

4. Summary

The data on KCl pellet injection into T-10 plasma have been simulated using 1D transport code. The main problem was to reproduce the fast cooling of plasma core after pellet injection as seen in experiments. A non-local response of thermal transport on perturbations being discussed for other machines could be considered for further studies.

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