THE JUMP OF TRANSPORT COEFFICIENTS AT THE ECRH SWITCH-ON OR SWITCH-OFF IN T-10

V.F.Andreev, Yu.N.Dnestrovskij, K.A.Razumova, A.V.Sushkov
Nuclear Fusion Institute, RRC Kurchatov Institute, Moscow, Russia

1.Introduction.

There are many experimental data now with fast response (faster than the diffusion time calculated by the power balance) of the electron transport on different perturbations: the propagation of the sawteeth heat waves [1]; the pulsed central heating in W7-AS [2]; the L-H transition in JET [3]; the pellet injection in RTP [4] and Tore-Supra [5]; the edge plasma heating [6] in TEXT and the pulsed ECRH in RTP [7]. Most impressive this effect have been observed at the impurity laser ablation for the edge plasma cooling in TEXT [8] and TFTR [9], where the edge cooling leads to the fast increase of the central temperature.

The aim of this work is the analysis of the transient process after the ECRH switch-on (-off) and creation of the mathematical model describing the non-local plasma response. Also we consider the statement of the inverse problem for the proposed model and reconstruction of the transport coefficients using the experimental data obtained from the transient stage.

2. The mathematical model of the transient process after the ECRH switch-on.

We write the equation for the electron temperature $T^S(r)$ at the steady state:

$$\frac{3}{2}\frac{\partial}{\partial t}\left(n^S T^S\right)=\frac{1}{r}\frac{\partial}{\partial r}\left(rn^S \chi_e^S \frac{\partial T^S}{\partial r}\right)-\frac{1}{r}\frac{\partial}{\partial r}\left(rn^S u_e^S T^S\right)+P_{OH}^S+Q^S=0. \qquad (1)$$

In parallel we write the equation for the electron temperature $T(r,t)$ at the transient stage:

$$\frac{3}{2}\frac{\partial}{\partial t}\left(nT\right)=\frac{1}{r}\frac{\partial}{\partial r}\left(rn\chi_e \frac{\partial T}{\partial r}\right)-\frac{1}{r}\frac{\partial}{\partial r}\left(rnu_e T\right)+P_{OH}+Q+P_{EC}. \qquad (2)$$

Here n is the electron density, P_{OH} is the Ohmic power, Q is the possible heat sink, χ_e is the heat diffusivity, u_e is the convective velocity. The index "*s*" marks the steady state values.

Represent the density and temperature as the sums of the steady state values $n^S(r)$, $T^S(r)$ and their variations $\tilde{n}(r,t)$ и $\tilde{T}(r,t)$: $n(r,t)=n^S(r)+\tilde{n}(r,t)$, $T(r,t)=T^S(r)+\tilde{T}(r,t)$.

Subtracting (1) from (2), we obtain the equation for the temperature variation $\tilde{T}(r,t)$:

$$\frac{3}{2}\frac{\partial}{\partial t}\left(n^S\tilde{T}\right)=\frac{1}{r}\frac{\partial}{\partial r}\left(rn^S\chi_e\frac{\partial\tilde{T}}{\partial r}\right)-\frac{1}{r}\frac{\partial}{\partial r}\left(rn^S u_e\tilde{T}\right)+P'_{OH}\cdot\tilde{T}+Q'\cdot\tilde{T}+ \\ +P_{EC}+\frac{1}{r}\frac{\partial}{\partial r}\left[rn^S(\chi_e-\chi_e^S)\frac{\partial T^S}{\partial r}\right]-\frac{1}{r}\frac{\partial}{\partial r}\left[rn^S(u_e-u_e^S)T^S\right] \qquad (3)$$

Here we used the following assumptions: a) the relative density variation is much less than the relative temperature variation; b) in the ohmic heating and sinks we omit the second order terms relative to the temperature variation.

3. The model of transport coefficients for the transient stage after ECRH switch-on(-off).

Main assumption for non-local plasma response at the ECRH switch-on (-off) is as follows: the transport coefficients can have jump-like change over the whole plasma cross section with the small characteristic time 100-200 μs. Represent the heat diffusivity χ_e and the convective velocity u_e: $\chi_e(r,t) = \chi_e^S(r) + \tilde{\chi}_e(r,t),\ u_e(r,t) = u_e^S(r) + \tilde{u}_e(r,t)$.

Substituting these formulas into (3), we obtain the equation for the transient stage:

$$\frac{3}{2}\frac{\partial}{\partial t}\left(n^S\tilde{T}\right) = \frac{1}{r}\frac{\partial}{\partial r}\left[rn^S\left(\chi_e^S + \tilde{\chi}_e\right)\frac{\partial\tilde{T}}{\partial r}\right] - \frac{1}{r}\frac{\partial}{\partial r}\left[rn^S\left(u_e^S + \tilde{u}_e\right)\tilde{T}\right] +$$

$$+ P'_{OH}\cdot\tilde{T} + Q'\cdot\tilde{T} + P_{EC} + \frac{1}{r}\frac{\partial}{\partial r}\left(rn^S\tilde{\chi}_e\frac{\partial T^S}{\partial r}\right) - \frac{1}{r}\frac{\partial}{\partial r}\left(rn^S\tilde{u}_e T^S\right), \qquad (4)$$

$$\partial\tilde{T}/\partial r\,(r=0,t) = 0,\ \tilde{T}(r=1,t) = 0,\ \tilde{T}(r,t=t_S) = 0,\ 0<r<1,\ t>t_S.$$

The terms defining by the jump of the transport coefficients are main peculiarities of Eq. (4). At the initial stage, when $\tilde{T} << T^S, \partial\tilde{T}/\partial r << \partial T^S/\partial r$, these terms are the main. The statement of the inverse problem and the algorithm of its solution one can find in [10-11].

4. Results of calculations.

Fig.1 and Fig.2 show the evolution of the variation SXR intensity for different radii after ECRH switch-on (t=670 ms) and switch-off (t=750 ms) in the shot #29614. It is well seen that the evolution of the central SXR intensity is opposite to the evolution of SXR intensity at the points, where the ECR power is deposited. So the transient process after the ECRH switch-on (-off) is an example of the non-local plasma response on the external action.

The problem of the transport coefficients reconstruction based on the model (4) can be simplified two different ways. In both we assume that the variation $\tilde{\chi}_e(r,t)$, $\tilde{u}_e(r,t)$ are only radial function and the total steady state heat flux has the diffusion part only, i.e. $u_e^S(r) \equiv 0$.

A) After the ECRH switch-on (-off) the coefficient $\chi_e(r,t)$ changes only. Thus the solution of the inverse problem allows us to reconstruct the coefficient $\chi_e^S(r) + \tilde{\chi}_e(r)$, the jump of the heat diffusivity $\tilde{\chi}_e(r)$ and the ECRH power profile $P_{EC}(r)$.

B) After the ECRH switch-on (-off) the convective velocity $u_e(r,t)$ changes only. Thus the solution of the inverse problem allows us to reconstruct the steady state coefficient $\chi_e^S(r)$, the jump of the convective velocity $\tilde{u}_e(r)$ and the ECRH power profile $P_{EC}(r)$.

Fig.3 shows the solution of inverse problem (A) (shot #23281, the ECRH switch-off at t=805 ms). Here radial dependencies of the total heat diffusivity χ_e (red line), the jump of the heat diffusivity $\tilde{\chi}_e$ (blue line) and the ECRH power P_{EC} (black line) are shown.

Fig.4 shows the solution of inverse problem (B) (shot #23281, the ECRH switch-off at t=805 ms). Here radial dependencies of the steady state heat diffusivity χ_e^S (red line), the jump of convective velocity $\tilde{u}_e$ (blue line) and the ECRH power P_{EC} (black line) are shown.

Fig.5 shows time dependencies of the experimental (black lines) and calculated (red lines) temperatures for several radii. The solution describes well the temperature increase at the plasma center and the temperature decrease in the place of the ECRH power.

Note, that we have no possibility to choose the unique solution from the two obtained, thus experimental data has high level of noises. It is possible to solve this problem if to use the additional experimental information. As example, it is well known that after the ECRH switch-on the part of plasma density is thrown out from the plasma core. This effect can be interpreted as the appearance of the additional convective flux. But to resolve this problem we need the detail experimental density and to use the equation for the density with the Eq. (4).

5. Conclusion

The transient process during the 10÷20 ms after the ECRH switch-on (-off) really consists of two different physical processes. The first one is the jump-like change of the transport coefficients over the whole plasma cross section and as a consequence the change of the initial steady state temperature distribution. The second one is the plasma heating.

The assumption on the jump-like change of the transport coefficient allows one to describe adequately the transient process after the ECRH switch-on (-off). The temperature decrease (increase) in the plasma core after the ECRH switch-on (-off) is explained by the increase (decrease) of the transport coefficients over the whole plasma cross section.

This work is supported by Russian Fund of Fundamental Researches, Grant № 00-15-96536, № 01-02-17483.

References.

1. E.D.Frederickson et al., Phys. Rev. Lett., **65** (1990) 2869.
2. U.Stroth et al., Proc. Worshop Varenna, 1993, Bologna, (1993) 161.
3. J.C.Cordey et al., Plasma Phys. Control. Fusion, **36** Suppl. 7 (1994) A267.
4. P.Mantica et. al, Proc. 24th Eur. Conf. Berchtesgaden, Vol.21A, Part IV (1997) 1853.
5. X.L.Zou et. al., Proc. 25th Eur. Conf. Prague, Vol.22C (1998) 655.
6. K.W.Gentle et al., Phys. Plasmas, **4** (1997) 3599.
7. P.Galli et al., Nucl. Fusion, **39** (1999) 1355.
8. K.W.Gentle et al., Phys. Plasmas, **2** (1995) 2292.
9. M.W.Kissick et al., Nucl. Fusion, **34** (1994) 349.
10. V.F.Andreev et al., Nucl. Fusion, **33** (1993) 499.
11. V.F.Andreev et al., Proc. 26-th Eur. Conf. Maastricht, ECA Vol.23J (1999) 853.

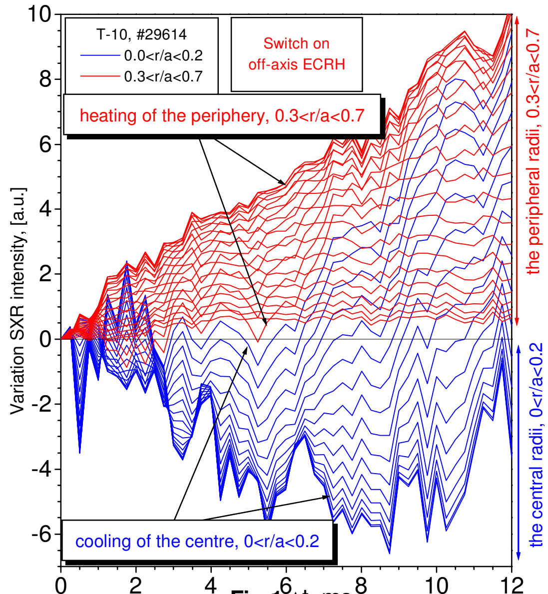

Fig.1.

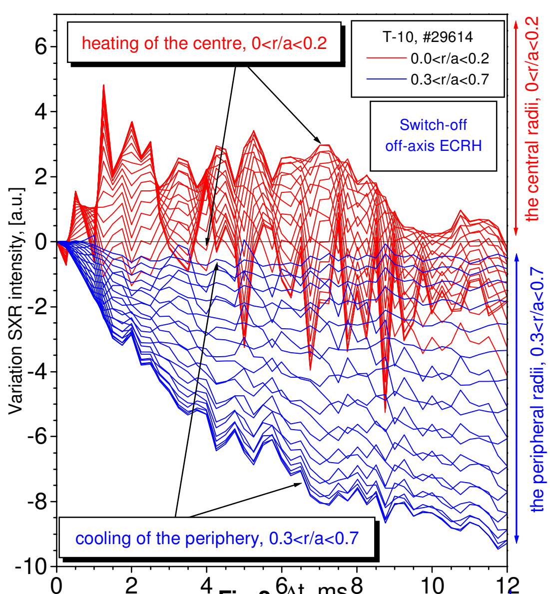

Fig.2.

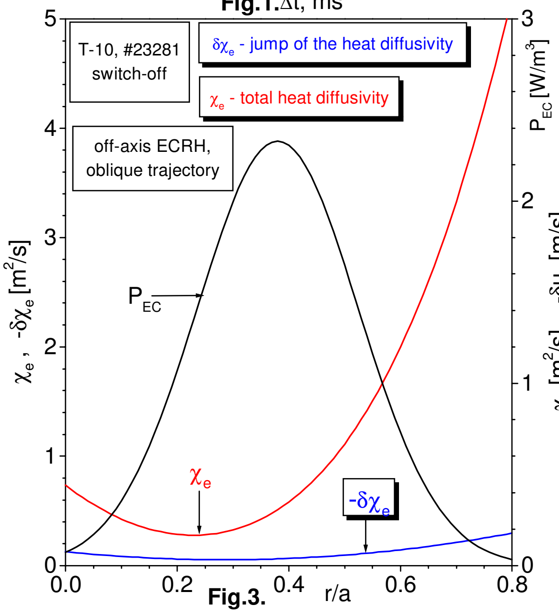

Fig.3.

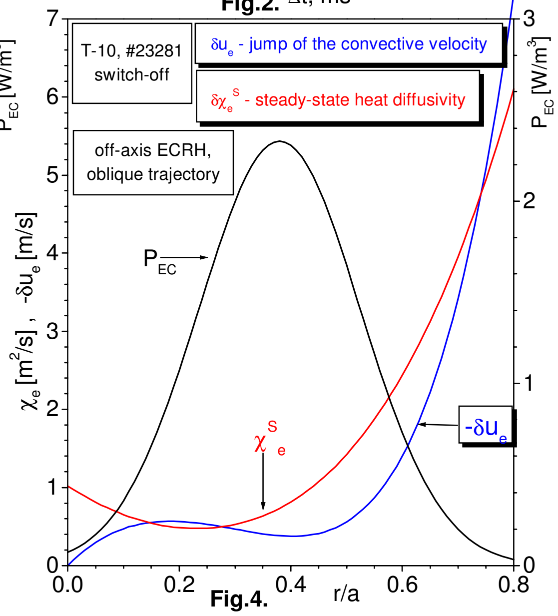

Fig.4.

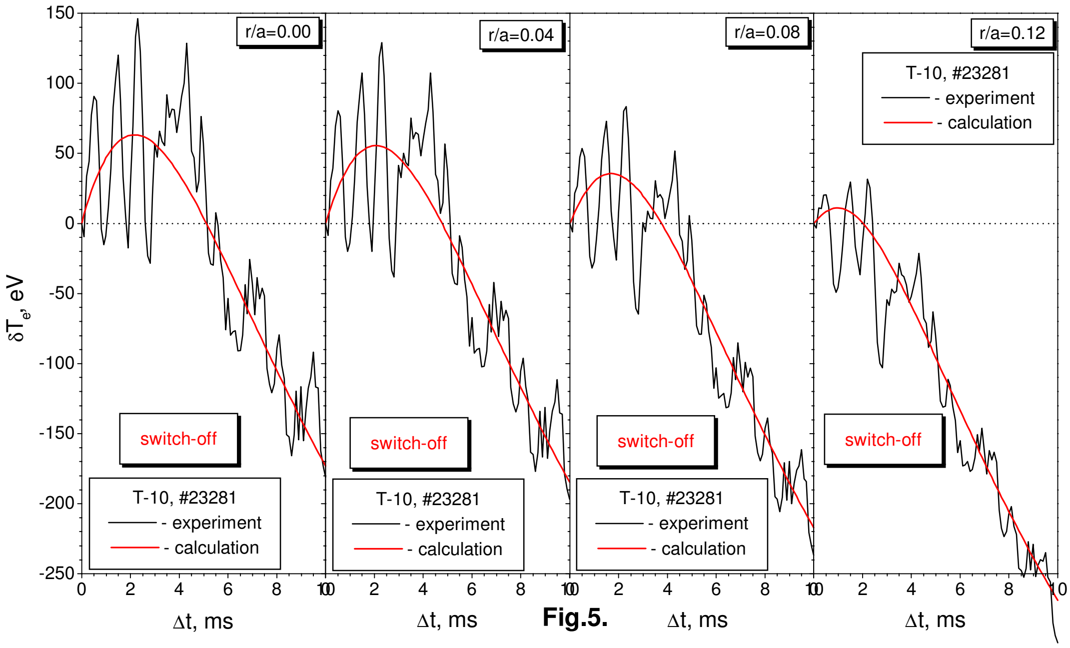

Fig.5.