EXPERIMENTAL TESTS OF TRANSPORT MODELS USING MODULATED ECH[*]

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Simulations have shown that perturbative transport experiments, where the dynamic plasma response is probed, can provide a more sensitive test of transport models compared to a comparison of measured and simulated temperature profiles from a power balance analysis. A perturbation source that deposits heat locally into the plasma particle species under study is preferred. Experiments have been performed on the DIII–D tokamak using modulated ECH as the perturbative heat source with the resonance layer off axis. The electron and ion response to the perturbation is measured and the amplitude and phase of the perturbations is compared to predictions from several transport models.

To avoid inherent plasma perturbations such as sawteeth and ELMs, an MHD quiescent discharge in an L–mode configuration, limited on the inside wall of the vacuum vessel, was chosen as the target plasma with a plasma current of 0.8 MA and electron density of $2 \times 10^{19} m^{-3}$. Early in the discharge, 4 MW of neutral beam power was applied to produce a sawtooth-free period during which 1 MW of ECH was applied in 20 ms pulses every 40 ms for a duration of 1 s. A toroidal field of 1.67 T resulted in second harmonic ECH power absorption (f_o = 110 GHz) at a normalized plasma radius ρ = 0.24–0.32.

The ECH heat pulse produced perturbations δT_e ~ 200 eV at the resonant layer, observed by monitoring electron cyclotron emission (Fig. 1). The pulse shape is consistent with integration of the applied heat pulse with some deviation from a linear rise due to transport during the heat pulse. The electron perturbation rapidly propagated to the plasma core with little phase shift while the amplitude was reduced to ~40 eV. The ion temperature dropped in response to the electron heat pulse. Fourier analysis of charge exchange recombination radiation indicated the ion response at the resonant layer is ~180° out of phase with the electron response and also rapidly propagated to the plasma core, maintaining its out of phase relation to δT_e. The amplitude of δT_i increased as the perturbations propagated to the plasma core, in contrast to a decrease in δT_e.

Several theoretical and empirical models for describing electron and ion thermal transport have been examined. Two models which represent extremes in stiffness, a strong dependence on temperature gradients, are the IFS/PPPL model [1] based on ion temperature gradient (ITG) mode turbulence which depends sensitively on a critical temperature gradient and the

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Itoh-Itoh-Fukayama (IIF) model [2] based on current diffusive ballooning mode theory which has no critical temperature gradient dependence. Simulations of the electron and ion temperature response to the ECH perturbation were performed with these and other similar models using a time-dependent transport code.

The predicted phase of δT_e and δT_i in the plasma core proved to be the most sensitive test for differentiating between the models. The ion phase is well described by the IFS/PPPL model whereas the IIF model best describes the observed electron phase behavior (Fig. 2). For the IFS/PPPL model, the T_i response is largely determined by the effect of the T_i/T_e ratio on the ITG mode threshold. As the electrons are heated at the ECH resonant layer, T_i/T_e decreases which in turn destabilizes the ITG-driven transport and thereby increases the ion transport at that location. This behavior is consistent with the observed ion response to the electron heat pulse. The model, however, incorrectly predicts a ~180^o phase shift in δT_e as it propagates inward from $\rho = 0.28$ to $\rho = 0.1$ whereas the experimental result is only a small phase shift. The IIF model agrees well with the electron phase behavior, but incorrectly predicts only a small phase shift for the ion pulse with respect to the electron pulse. Both model predictions were in fair agreement with the δT_e amplitudes observed at the resonant layer but are up to a factor 4–5 too large in the plasma core (Fig. 1). Model predictions for δT_i amplitudes were a factor 2–4 larger than measured in the plasma core.

The overall observations indicate that the electron and ion responses to the ECH perturbation are out of phase with each other at the plasma core and at the resonance layer. None of the transport models studied predicts this characteristic at the plasma core and thus the experiment remains a challenge to the modeling community.

[1] KOTCHENREUTHER, M., et al. Phys. Plasmas **2**, 2381 (1995).

[2] ITOH, S.I., et al., Phys. Rev Lett. **72**, 1200 (1994).

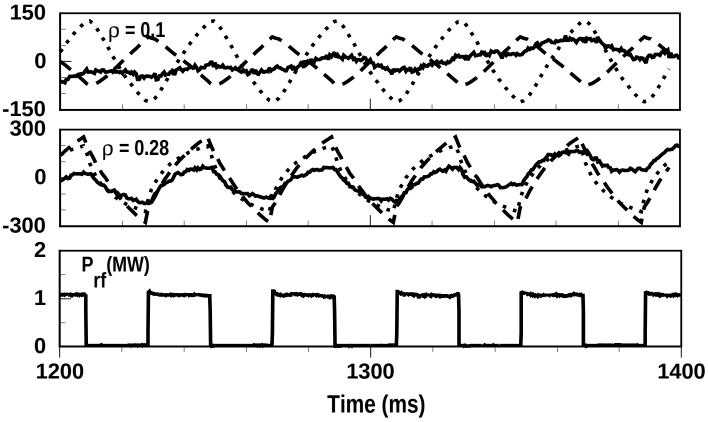

Fig. 1. δT_e (eV) at $\rho = 0.28$ and $\rho = 0.1$ for measured data (solid line), and simulated data from the IFS/PPPL model (dashed line), and IIF model (dotted line).

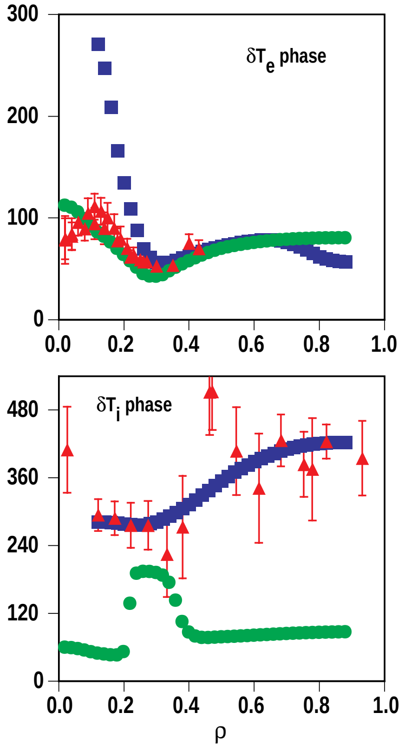

Fig. 2. Fourier analysis of phase for δT_e and δT_i for measured data (triangles), IFS/PPPL model (squares) and IIF model (circles).