Search for a Critical Electron Temperature Gradient in DIII-D L-Mode*

EX-C

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Experiments in DIII-D using a novel technique to modulate the local electron temperature gradient show no evidence of a thermal diffusivity dependent on a critical temperature gradient scale length. These results are consistent with previous experiments on DIII-D [1] where modulated ECH used to probe the T_e profile showed no evidence of nonlinear behavior, but are in contrast to experiments on other tokamaks, notably ASDEX-Upgrade [2], where a model of the form $\chi_e = \chi_o + f(T_e)[(\nabla T_e/T_e)-k_{crit}]H_k$ has been successful in describing electron transport. The model shows that the incremental or heat pulse diffusivity, $\chi_e^{HP} \equiv \partial(\chi_e \nabla T_e)/\partial \nabla T_e = \chi_o + f(T_e)[2(\nabla T_e/T_e)-k_{crit}]H_k$ undergoes a discontinuous increase when the local T_e gradient scale length, $L_{Te}^{-1} = \nabla T_e/T_e$, exceeds a critical value, k_{crit}, and the Heaviside function becomes nonzero. This jump in χ^{HP} produces a nonlinear change in T_e as k_{crit} is exceeded. The recent experiments in DIII-D show no evidence of a nonlinear response in T_e due to local modulation of ∇T_e.

The DIII-D experiments were designed to search for evidence of the existence of k_{crit} utilizing a novel technique first employed on FTU [3]. The technique utilizes two different EC heat pulse trains, ECH1 and ECH2, each absorbed at slightly different radii and modulated out of phase with respect to each other in order to maximize the change in ∇T_e at a constant total input power (Fig. 1). This keeps the overall T_e profile roughly constant outside the probed region while locally changing ∇T_e. In the deposition region where ECH1 and ECH2 overlap, the EC power is constant and thus no modulation in T_e is expected if the two heat pulses simply linearly combine. However if nonlinear changes in χ^{HP} occur they will modulate T_e and produce a non-zero amplitude in the Fourier analyzed T_e response.

The experiments were carried out in sawtooth-free, L-mode discharges limited on the inside wall of the vessel to prevent transitions to H-mode with $P_{ECH1} \sim P_{ECH2} \sim 1$ MW square

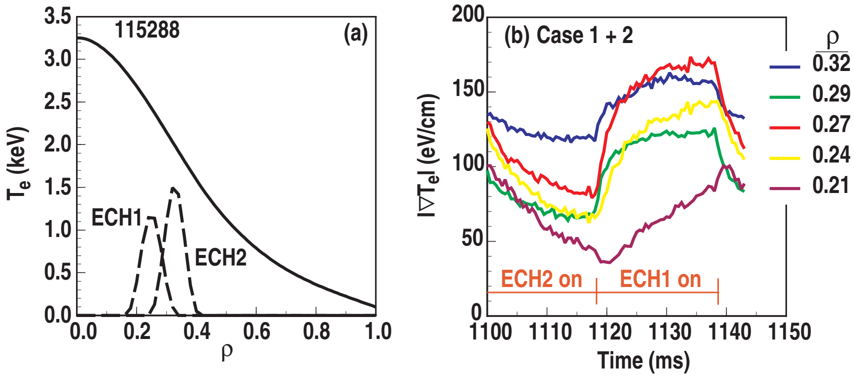

Fig. 1. (a) Temperature profile and (b) temperature gradient variation for the Ohmic discharges produced by electron cyclotron heat pulses, ECH1 and ECH2, applied at 25 Hz and out of phase with respect to each other.

*Work supported by U.S. Department of Energy under DE-FC02-04ER54698, DE-FG03-97ER54415, and DE-FG02-92ER54141.

wave modulated at 25 Hz with a 50% duty cycle. The T_e profile was probed at two spatial locations, $\rho_{ECH} = 0.2\text{-}0.3$ and 0.4-0.5, and at the inner location three heat flux conditions were tested with 0, 2.8 and 4.0 MW NBI. At each condition three discharges were taken, one with ECH1 and ECH2 modulated out of phase (case 1+2) and then one each with ECH1 modulated and ECH2 CW at half power (labeled case 1) and vice versa (labeled case 2). Cases 1 and 2 are executed with the CW source at half power in order to keep the total average power fixed, making the plasma profiles very similar in all three cases.

The maximum change in ∇T_e was produced in the Ohmic condition with $\rho_{ECH} \sim 0.2\text{-}0.3$ (Fig. 1). The gradient is determined by differencing adjacent channels of the electron cyclotron emission system after first averaging over nine modulation periods. The relative change in ∇T_e was over 100% in the Ohmic case with smaller changes produced in the cases with NBI power and larger ρ_{ECH}, making these cases less likely to exceed a critical value.

No evidence of a nonlinear response in T_e was observed in the Ohmic case where it was expected that such a response was most likely to occur nor in any of the other cases studied, consistent with earlier experiments [1]. The detailed search for evidence of nonlinear behavior was carried out by comparing the Fourier analyzed amplitude and phase of the T_e modulations from Case 1+2 to a calculation of the linear combination of Fourier amplitudes and phases from Case 1 and Case 2 (Fig. 2). The clearest evidence for nonlinear behavior would be an amplitude in Case 1+2 considerably larger than the simple linear combination of Case 1 and Case 2 in the overlap region between ECH1 and ECH2 where the simple linear combination gives a very small amplitude as expected due to ECH1 and ECH2 being out of phase. As shown in Fig. 2 the amplitude and phase in Case 1+2 is the same as the linear combination, indicating no nonlinear behavior in χ^{HP} is required to understand the T_e response to the applied heat pulses.

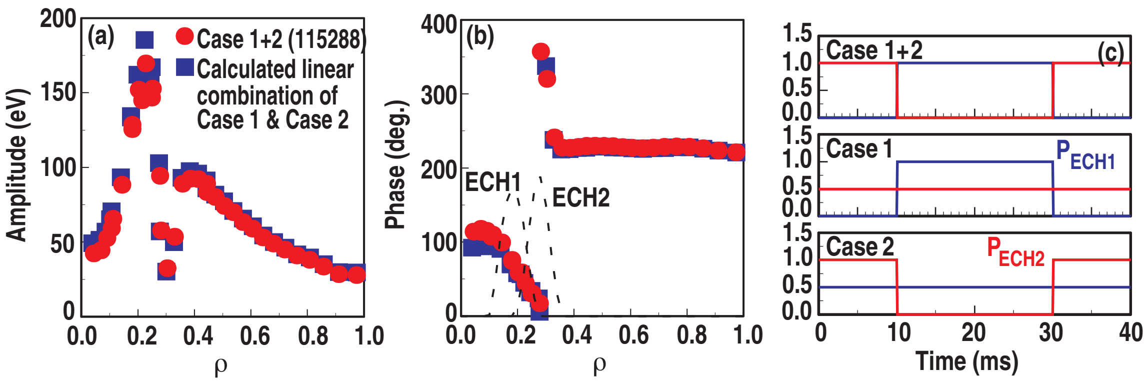

Fig. 2. (a) Fourier amplitude and (b) phase components of the electron temperature response for the Ohmic case with ECH1 and ECH2 applied out of phase with respect to each other (circles) and applied individually and then linearly combined (squares). (c) Power modulation for the three cases.

Modeling of the measured pulse propagation characteristics indicates that a step in χ^{HP} is consistent with the pulse amplitude in Case 2 but two steps are required to obtain agreement with the pulse amplitude in Case 1 and the phase is not well matched in either case. The same model cannot explain Case 1+2, specifically designed to look for nonlinear behavior.

Results of these experiments on DIII-D remain at odds with those performed on other tokamaks, particularly those on ASDEX-Upgrade. Since these two devices are very similar it is hoped that coordinated, common experiments planned on each device for the near future will help identify the important physics responsible for the differing results and thus lead to an overall improvement in understanding electron transport in tokamaks.

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