Propagation of cold pulses produced by laser blow-off impurity injection in the TJ-II stellarator

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Introduction

The study of cold pulse propagation, caused either by laser blow-off or pellet injection, has shown that the electron energy transport has a local character in the W7-AS stellarator[1] and the RFP reversed-pinch,[2] in contrast to the LHD stellarator[3] and tokamaks as TEXT[4] and JET,[5] which exhibited non-local behaviours.

Cold pulse propagation was previously studied with nitrogen puffing in the TJ-II stellarator plasma.[6] In this contribution, we have used a different impurity injection method based on the laser blow-off[7] technique for addressing a similar purpose, but with the possibility of covering cases with a better control of the perturbation size and the deposition radius. In this work, we present a method to determine the delay and decay time of the perturbation as seen by the Electron Cyclotron Emission (ECE) radiometer and study its behaviour for a few discharges with different plasma densities.

Experimental

TJ-II is a four-period, low magnetic shear stellarator with major and averaged minor radii of 1.5 m and $\leq$ 22 cm, respectively. Central electron densities and temperatures up to 1.7×10^{19} m^{-3} and 1 keV respectively are achieved for plasmas created and maintained by Electron Cyclotron Resonance Heating (ECRH) at the second harmonic (f = 53.2 GHz, $P_{ECRH} \approx 400$ kW). Laser blow-off injection was performed with a light element boron as a tracer. The boron was deposited on glass samples as a thin film of thickness 2 μm. The samples were deposited at the University of California, San Diego using a magnetron. The thin film was blown off by a Q-switched Nd-YAG laser beam (800 mJ, 10 ns), which was focused to a spot of diameter 1 mm[8].

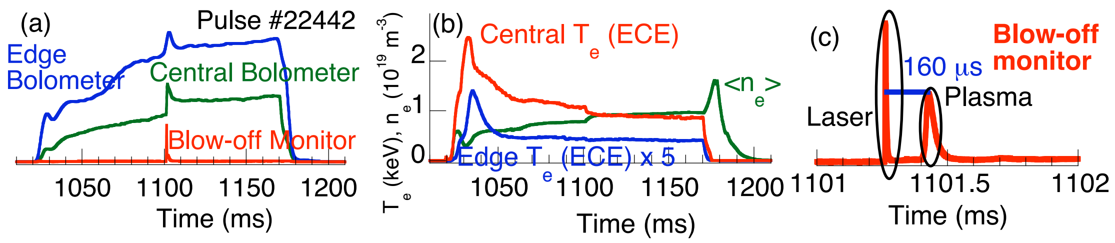

Figure 1. (a) Blow-off monitor and bolometer signals in a discharge with blow-off injection. (b) ECE channels for same discharge. (c) Blow-off monitor for the injection time: the first sharp peak indicates the laser shot and the second peak when the ablated particles interact with the plasma edge.

In order to track the cold front time evolution, we focused our analysis on the blow-off monitor (a fast light detector at the injection port) for timing the laser shot and the arrival of the injected particles at the plasma edge, and on the multichannel heterodyne ECE radiometer. The latter followed the temperature perturbation at different radii with good temporal resolution.[9] The ECE signal acquisition rate was 100 kHz.

In figure 1, we show a typical TJ-II discharge where boron was injected at 1100 ms. The effects produced by the impurity injection in a central and a peripheral bolometer, as well as in ECE monitors in similar radial positions, are depicted in figures 1(a) and 1(b), respectively. Figure 1(c) shows an expanded view of the injection monitor, where the time elapsed between the laser shot and the arrival of the plume to the plasma edge is clearly visible, permitting an estimate of the average impurity velocity.

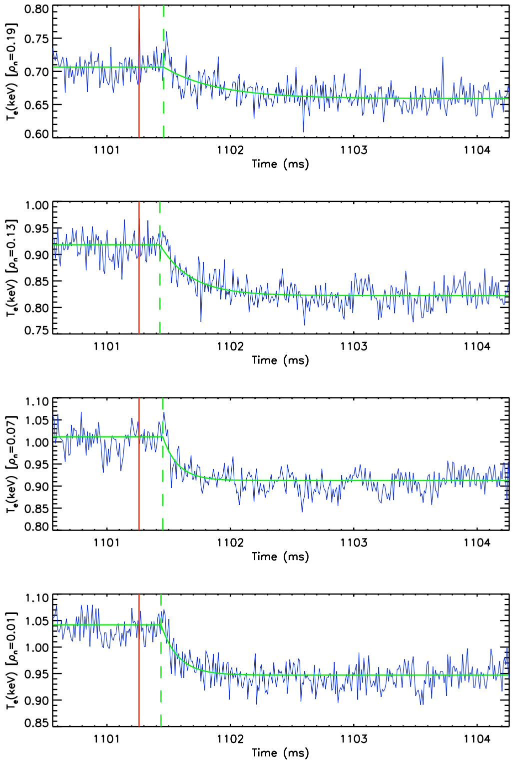

Figure 2. Analysis of ECE channels in discharge #22442. The perturbation is fitted to an exponential decay. The blue line is T_e measured with the ECE radiometer; the vertical red line indicates the laser shot (t_{blow}); the vertical solid green line is t_0; and the solid green line is the fitted function (1).

Data analysis

To calculate the perturbation delay and decay time for the ECE channels, we followed a process that consisted of several steps. Firstly, we determined the analysis time window, where the ECE signal is transiently perturbed before reaching its final level. After this, we extracted the transient ECE temporal shape by subtracting the trace of a reference discharge, that was scaled to the current signal level and incremented so that reference signal was zero outside the perturbation zone. The resulting signal was fitted to the function:

$$T_e(t) \;=\; T_{e0} \;+\; H(t-t_0)(T_{e1}-T_{e0})\;(1-e^{-t/\tau}) \qquad (1)$$

where $H(t)$ is the Heaviside function. In this expression, T_{e0} and T_{e1} were calculated as the mean of the ECE signal at the beginning and the end of the analysis window, respectively. After this, the decay time, τ, was determined with a non-linear least squares fit of the ECE data in the time interval of the perturbation. Finally, the delay time, t_0, was fitted with a non-linear least squares fit in the full analysis time window. The reason to calculate the parameters in several steps is that each step is very robust, and we reduced the uncertainties introduced when fitting simultaneously several free parameters.

Results and discussion

The described method was applied to discharge #22442 (figure 2) and the parameters t_0 and τ which were obtained are shown in figure 3. Since the larger radius channels did not experience a significant enough change to allow a reliable fit, we have focused our analysis on the 4 more internal ECE channels. We note that t_0, see figure 3(a), is very similar for all the 4 central channels, indicative that the perturbation is felt at almost simultaneously for all central channels; i.e. there was no detected propagation. A more clear difference is seen in figure 3(b) for τ, which is shorter as we move toward the plasma center.

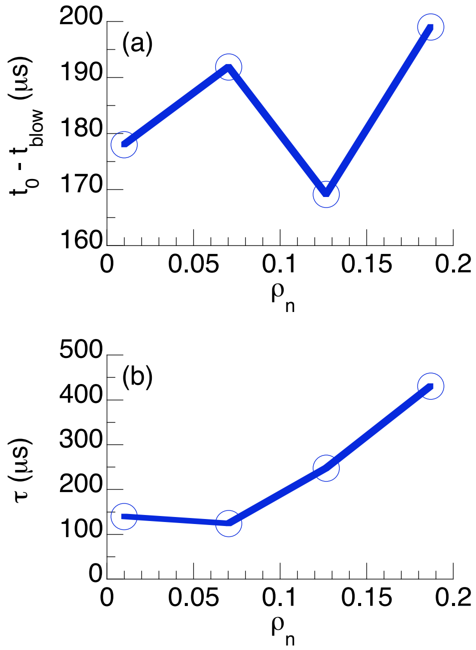

Figure 3. (a) t_0 (delay times) and (b) τ (decay times) for ECE channels after blow-off injection in discharge #22442. The difference in t_0 between the channels is not significant ($\Delta t_0 \sim 100$ μs).

This type of analysis was carried out for otherwise similar discharges but with three different electron densities. The parameters of the fitting, t_0 and τ, are plotted versus the line-averaged density in figure 4(a) and 4(b), whereas figure 4(c) depicts the change of central temperature in this sequence of discharges.

These results are different than those previously obtained,[6] where the propagation was studied producing the electron temperature transient by a strong nitrogen puffing. In that

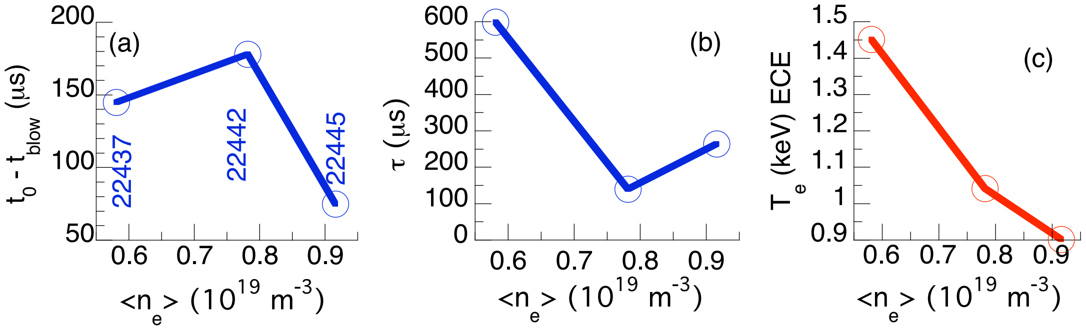

Figure 4. Analysis of central ECE channel ($\rho_n = 0.01$) in blow-off injections for discharges with similar plasma configuration: (a) t_0, (b) τ and (c) central T_e are shown as function of the averaged electron density ($<n_e>$) before injection.

case, the edge ECE channels responded significantly faster than the central ones, with delays of ≈2 ms. This suggest that the underlying physics is very different for the case of blow-off injection and gas puffing, presumably because in the former case the T_e perturbation is introduced very rapidly in a toroidally localized region.

To understand better our results, further studies should be carried out including a broader range of plasma discharges with different level of blow-off perturbation and different magnetic configurations.

Acknowledgements

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