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Characteristic of Thermal Quench and its Interpretive JOREK Simulation in EAST Disruptions

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During a thermal quench (TQ), the stored thermal energy is released over a short timescale, posing a significant risk of damage to plasma-facing components (PFCs), particularly in future large-scale tokamaks. This energy loss is generally attributed to the formation of a global stochastic magnetic field. However, the stochastic field does not materialize instantaneously; instead, it emerges progressively through distinct magnetohydrodynamic (MHD) modes coupling, which in turn shape the characteristics of thermal-energy loss.

To characterize these dynamics, we have constructed a database of TQ events from EAST disruptions. Major-disruption TQ durations span 60-800 μs and fall into two typical behaviors. In single-stage TQ, a fast-loss stage is triggered by magnetic perturbation exceeding 4.3×10^{-3} T with a fast growth rate of 1.5×10^{-2} μs^{-1}. In double-stage TQ, fast quench is triggered by a slightly smaller magnetic perturbation of 3.6×10^{-3} T, and the growth rate 5.3×10^{-3} μs^{-1} is an order of magnitude smaller than single-stage TQ. These distinctions highlight how specific MHD mode interactions govern both the pace and structure of thermal-energy loss.

To explore the underlying physics, we performed JOREK simulations with non-equilibrium impurity treatment, focusing on the TQ triggered by massive neon gas injection in EAST L-mode disruptions. The simulations reproduce both double-stage and single-stage TQ observed in EAST experiments, with variations in impurity particle fluxes. In double-stage TQ, non-linear interactions between the m/n = 3/1, 4/1, and 5/1 modes primarily contribute to edge stochasticity. The growth of the m/n = 2/1 mode initiates core energy loss during the initial temperature collapse, and the release of free energy moderates subsequent MHD activity, somewhat prolonging the energy loss time. Later, the m/n = 2/1 mode, with comparable amplitude, along with higher harmonics, couples with the 3/1 mode, resulting in a global stochastic process and total energy loss during the second collapse. The transition from double-stage to single-stage TQ is mainly determined by the growth rate of the n = 1 mode. Our simulations indicate that the longer duration of double-stage TQ offers benefits for reducing the peak power of outward energy flux. Finally, the strike point splitting on the upper-outer target, observed experimentally, is also reproduced in the simulations. These findings deepen our understanding of the TQ process and provide new insights into disruption mitigation strategies.

References

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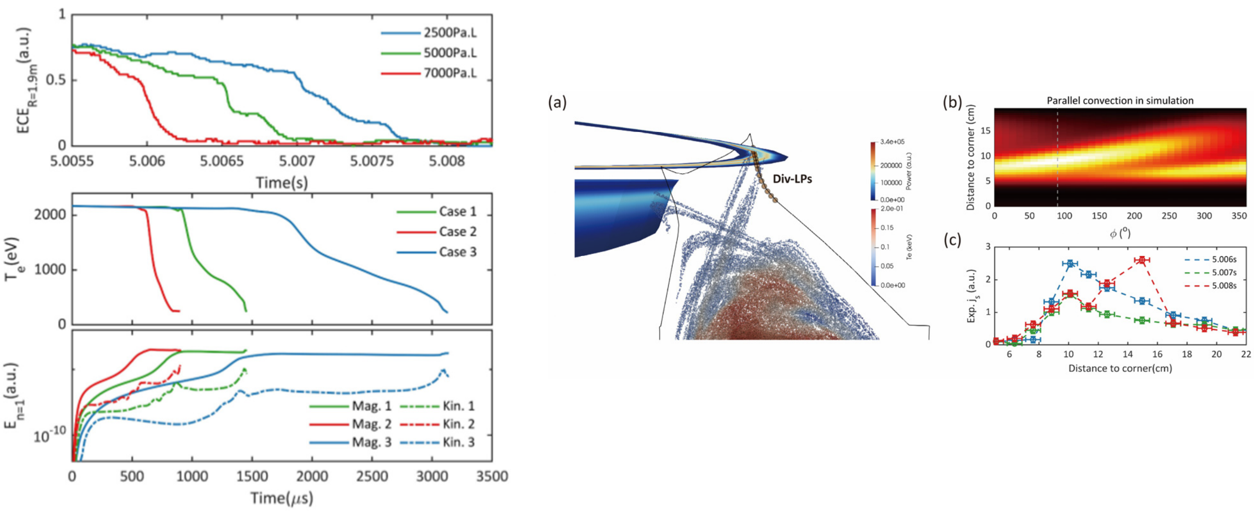

Figure 1. The transition from double-stage to single-stage TQ (left) and the strike point splitting on the upper-outer target (right) in experiment and simulation.