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Thermal transport induced by stochastic magnetic fields during fast thermal quench in tokamak plasmas

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The timescale of the thermal quench (TQ) stage of the tokamak disruption is always the focus of attention. Generally the whole TQ stage can be further divided into the initial 1-2 delay stage and the final fast quench stage, in which a large flattening of the temperature profile is followed by a decrease of the flattened profile[1]. It is widely recognized that the TQ timescale is closely related to the stochastic magnetic fields induced heat diffusion, but there are still some open issues to be elucidated. On the one hand, from the statistical result of the IDDB (ITER disruption database), the 1-2 delay time τ_{1-2} and the fast quench time τ_2 are roughly scaling with the minor radius a as $\tau_{1-2} \propto a^{1.5}$ and $\tau_2 \propto a^1$, respectively[2]. The timescale of non-linear interactions of 1/1, 3/2 and 2/1 magnetic islands agrees well with the 1-2 delay time[3], while the scaling of the fast quench time is not fully understood yet. On the other hand, the range of plasma temperature involving in the fast TQ stage is quite large, mainly because: (a) The core electron temperature can reach the order of several keV before the onset of fast TQ, while the temperature at the boundary is only at hundreds of eV or less; (b) After thermal collapse, the plasma temperature can drop by one or two orders of magnitude. Therefore, the thermal transport process involves multiple collisional regimes[4], which requires a heat diffusivity expression valid in a wide collisional parameter range for analyzing.

In this work, we focus on the timescale of fast TQ in tokamak locked mode disruptions in order to understand the physical mechanism of fast thermal transport during this stage. A general expression of electron thermal diffusivity has been obtained by connection the thermal diffusivity induced by stochastic magnetic fields in multiple collisional regimes, which can be applicable to a wide range of collisional parameters. The dependence of this general diffusivity on electron temperature, density and plasmas size has been analyzed, which provides a possible explanation for the linear scaling of the fast TQ timescale in the plasma minor radius. With different tokamak parameters, the characteristic timescales of fast TQ are quantitatively calculated based on the general electron heat diffusivity. It has been found that the electron temperature profile can be rapidly collapsed in less than 1 ms in the initial stage of fast TQ. However, the fast thermal transport cannot be maintained due to flattening of the electron temperature profile. This may indicate that other fast transport mechanisms, such as heat convection, nonlocal transport, and so on are necessary to maintain the fast TQ, which are left for future work.

References

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