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Heat transport induced by stochastic magnetic fields and electromagnetic turbulence during the fast thermal quench

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The timescale of the fast thermal quench (TQ) has been a long-lasting issue in tokamak plasmas, which is a key to the mitigation of the heat loads during the major disruptions in tokamak plasmas. The ITER disruption database has shown that the fast TQ timescale is roughly scaling with the minor radius a[1]. However, this scaling has not been fully understood yet.

It is generally believed that the global stochastic magnetic fields (SMFs) dominate the heat transport mechanism during the fast TQ stage. Previously, we derived a general electron heat diffusivity induced by the SMFs, which is applicable to multiple collisional regimes[2]. Based on this general heat diffusivity, the evolution of the electron temperature profile and the characteristic timescale of the fast TQ are quantitatively calculated under different tokamak parameters. It is found that the timescale is reduced (enhanced) by increasing the initial electron temperature (plasma size), which is qualitatively consistent with the experimental observations[3]. The linear scaling can be satisfied across tokamak devices with different sizes for initial fast TQ phase and fixed aspect ratio. Figure 1 demonstrates the dependence of the fast TQ timescale τ_{90-20} on the initial core temperature $T_{e,core}$ and compares the timescales obtained by employing the general diffusivity and the collisionless diffusivity. The significant difference at low temperature suggests that the collisionless diffusivity which is widely employed in fluid codes for the disruption simulation is needed to be modified. However, the fast outward heat transport cannot be maintained only via the heat diffusion mechanism in late TQ phase.

Recent Bout++ simulation results have shown that the heat flux caused by E×B velocity fluctuation during TQ can be comparable to that caused by the SMFs induced heat diffusion[4], indicating that it is necessary to take the role of electromagnetic turbulence into account. Moreover, the general heat diffusivity caused by SMFs in our previous work is obtained under the condition of weak SMFs. We further extend it by including the scattering effect caused by SMFs, electromagnetic turbulence and collision, which can be applicable to strong electromagnetic turbulence case. The main results show that: (1) Under the condition of weak SMFs, the fluctuating E×B velocity will cooperate with the SMFs to cause heat diffusion. If the effect of fluctuation E×B velocity is ignored, the results of our previous work can be recovered[2]; (2) Under the condition of strong SMFs, the formation of the heat flux is exactly the same as that under the condition of weak SMFs, but the scaling of the magnetic field line diffusivity with the normalized magnetic perturbation amplitude is linear rather than quadratic; (3) E×B transport will not only directly induce the heat diffusion, but also modify the decorrelation process of diffusion caused by SMFs.

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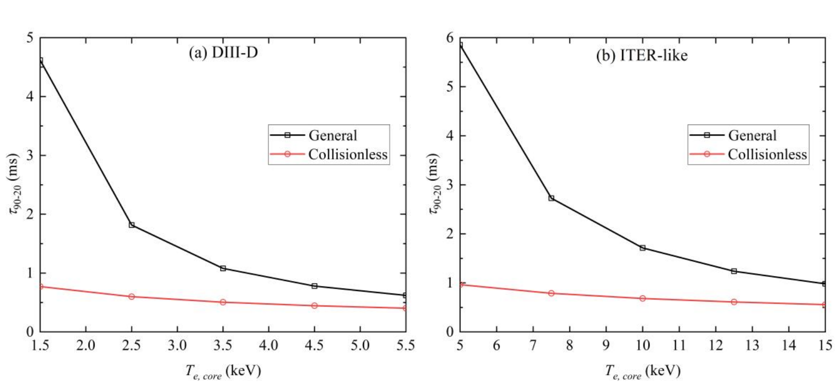

Figure 1. For typical DIII-D (a) and ITER-like (b) parameters, the dependence of the timescale of the fast τ_{90-20} on the initial $T_{e,core}$ using the general heat diffusivity (black line with square) is compared as to that using the collisionless heat diffusivity (red line with circle)