Control of runaway electron energy using externally injected whistler waves

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Runaway electrons present a challenge for disruption mitigation, especially for reactor-size tokamaks such as ITER, which is designed to have about 15 mega-ampere of plasma current. One way of mitigating runaway damage of the plasma-facing components is by limiting the runaway electron energy under a few MeV, while not necessarily reducing the runaway current appreciably. Recently we have reported a physics mechanism by which such momentum space engineering of the runaway distribution can be facilitated by externally injected whistler waves [1]. The drastic impact that wave-induced scattering can have on the runaway energy distribution is fundamentally the result of its ability to control the runaway vortex in the momentum space. The runaway vortex [2], which is a local circulation of runaways in momentum space, is the outcome of the competition between Coulomb collisions, synchrotron radiation damping, and runaway acceleration by parallel electric field. By introducing a wave that resonantly interacts with runaways at a particular range of energy that is mildly relativistic, the enhanced scattering would reshape the vortex by cutting off the highly-relativistic part. The efficiency of resonant scattering accentuates the requirement that the wave amplitude can be small so the power requirement from external wave injection is practical for the mitigation scheme.

In a tokamak geometry, the electrons with high pitch-angle can become magnetically trapped and thus will not be further accelerated by the parallel electric field. It has been pointed out [3] that the avalanche growth rate is effectively reduced for off-axis locations. From our study of the momentum-space topology modifications due to whistler waves in slab geometry, we find that the O and X points of the runaway vortex can both be lifted to higher pitches. Therefore, additional reduction of runaway avalanche rate should happen in a tokamak when wave-induced pitch-angle scattering send the O point into the trap-region where electrons are no longer accelerated. It is then expected that in a tokamak, the production rate of highly relativistic electrons will be further reduced because of the combined effects of wave-particle scattering and magnetic trapping. The LAPS-RFP code has been extended to include a bounce-average formulation which removes the fast transit/bounce time-scale of the relativistic electrons for numerical efficiency. We will report our detailed analysis of how toroidicity affects the momentum-space topology, and the resulting effects on the growth rate and the distribution function of runaway electrons.

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[1] Z.H. Guo, et. al., POP, accepted (2018)
[2] Z.H. Guo, et. al., PPCF, (2017)
[3] L.G. Eriksson et. al., CPC 154 (2003), E. Nilsson et. al., PPCF 57 (2015)