Runaway electron distribution functions in momentum space with the synchrotron radiation effect

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Runaway electron physics is an important aspect of the post thermal collapse in disruptions, and is a critical area for current research. Recently there have been several experiments dedicated to runaway electron generation, and the results seem to indicate that the critical electric field exceeds the Connor-Hastie critical electric field E_c by at least a factor of three. [1] The important physics effects, in addition to the Coulomb drag force, are synchrotron radiation, pitch-angle scattering, and the avalanche mechanism. In this study, we focus at first on the effect of synchrotron radiation. In the classical runaway electron theory, the runaway electron energy is affected by the electric field and the collisional drag force. When E is less than the Connor-Hastie critical field E_c, the runaway electrons will lose energy until they join the Maxwellian distribution. On the other hand, the synchrotron radiation of the electrons can produce a back-reaction force on the runaway electrons and cause energy loss. For E/E_c on the order of but larger than unity, the back-reaction force is comparable to the driving electric field and the collisional drag. Therefore the runaway electrons will be subject to an energy limit and the distribution will finally reach a steady state. Here we present a calculation of the steady state runaway electron distribution including the synchrotron radiation effects and quantitatively compare to related work on this subject. [2, 3] The numerical methods follow [4], with the addition of a self-consistent synchrotron radiation force into the kinetic equation for electrons. At present we only consider the Dreicer runaway electron generation and do not include the secondary runaway electron generation. The results show that there exists a higher critical electric field E_s. When E is below E_s, the steady state runaway tail decays exponentially and the total number of runaway electrons is very small. When E is above E_s, the runaway electron distribution will form a bump-on-tail (in the parallel direction and when integrated over pitch angle) before exhibiting exponential decay. The steady state distribution shows clear energy balance between the electric field, the drag force, and the radiation back-reaction force. This result is also quantitatively consistent with a test-particle model in which the various forces will form attractors in the momentum space of runaway electrons [2]. We also found that the runaway growth rate is significantly decreased by the radiation force when E/E_c is not much greater than 1. These results can help explain the recent experimental results [1] that the critical electric field found at which the runaway electron signal starts to decay is several times larger than the Connor-Hastie critical field.

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