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Theory and Simulation of the Electron Cyclotron Drift Instability

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In the vicinity of the X-type neutral line region, a characteristic scale length is shorter than ion inertia length but longer than electron inertia length, so that electrons are assumed to be magnetized but ions are unmagnetized. In this region, electrons can be accelerated up to the 'electron Alfven velocity' beyond the ordinary 'Alfven velocity' (e.g. Hoshino et al., 2001). This electron flow across the ambient magnetic field is super Alfvenic. We study possible instabilities excited by such a cross-field super Alfvenic electron beam. We discuss this problem in the frame of reference of the electron beam so as to vanish the uniform electric field. In this frame a cross-field super Alfvenic ion beam replaces the electron beam.

A series of 2-1/2 dimensional electromagnetic particle simulations were performed to investigate the instabilities excited by cross-field ion beam. We also performed the linear analysis in a condition that electrons are magnetized but ions are unmagnetized, and found two instabilities to be excited. They are the modified two-stream instability in the lower hybrid frequency regime and the electron cyclotron drift instability in the upper hybrid frequency regime. The results of our numerical simulation indicate that the former (the latter) is dominant when the ion beam velocity is under (above) the electron thermal velocity. Also, we found that the growth rates of unstable waves are consistent with the linear theory for both modes.

The modified two-stream instability caused the field aligned heating of the magnetized electrons by the electrostatic waves which propagate obliquely to the magnetic field. On the other hand, the electron cyclotron drift instability caused the perpendicular heating of electrons, which is due to particle trapping by the electrostatic potential of the waves, propagating nearly perpendicularly to the magnetic field.

Furthermore, our numerical simulation and the linear theory indicate that the range of propagation of unstable waves excited by the electron cyclotron drift instability becomes wider to a field aligned direction when the beam velocity increases. This attributes to the fact that this instability is due to the resonance between the electron Bernstein wave and the beam ions. Namely, the electron Bernstein wave with a low phase velocity propagates only to a confined direction nearly perpendicular to the magnetic field, but that with a high phase velocity can propagate more obliquely to the magnetic field. The phase velocity of the resonant wave becomes higher when the beam velocity increases, then the resonant range becomes wider as well. In such a way, the propagation range of the instability waves becomes wider with increase of the beam velocity.

Another significant result of the linear theory is that the electron cyclotron drift instability is destabilized by the electromagnetic effects, contrary to the modified two-stream instability which is stabilized by this effect.

We further studied the time development of the anomalous resistivity with our numerical simulation. The results show that the anomalous resistivity of the electron cyclotron drift instability is comparable with that of the modified two-stream instability. This is consistent with the prediction of the quasilinear theory. We conclude that the electron cyclotron drift instability plays an important role in the energy dissipation in a high velocity beam system.