Conversion of magnetic energy to plasma kinetic energy during guide field magnetic reconnection in the laboratory

Sayak Bose[1], Will Fox[1], Hantao Ji[1,2], Jongsoo Yoo[1], Aaron Goodman[2], Andy Alt[2], and Masaaki Yamada[1]
[1]Princeton Plasma Physics Laboratory, [2]Princeton University, Princeton
e-mail (speaker): sbose@princeton.edu

Magnetic reconnection is a fundamental process in plasmas that lead to a change in the topology of the magnetic field accompanied by the conversion of the stored magnetic energy to the plasma kinetic energy. Often reconnection in fusion plasmas [1,2], solar wind [3], solar flares [4], and in the earth's magnetosphere [5-8] proceeds in the presence of a finite Guide Field (GF) such that the magnetic field lines meet at an angle less than 180^0. In these places, GF reconnection is observed to energize electrons and ions.

We have experimentally studied the conversion of the magnetic energy to the plasma kinetic energy and the associated particle dynamics during guide field reconnection in the two fluid regime [9]. The experiments are conducted in the Magnetic Reconnection eXperiment (MRX) [10] at the Princeton Plasma Physics Laboratory. The upstream reconnecting magnetic field is comparable to the guide field. To understand the mechanism of energy conversion, we measured and compared 2-D profiles of key energy deposition scaler products, $\boldsymbol{J}.\boldsymbol{E}'$, $\boldsymbol{J_e}.\boldsymbol{E}$, $\boldsymbol{J}_{\boldsymbol{e},\parallel}.\boldsymbol{E}_\parallel$, $\boldsymbol{J}_{\boldsymbol{e},\perp}.\boldsymbol{E}_\perp$, $\boldsymbol{J_i}.\boldsymbol{E}$, $\boldsymbol{J}_{\boldsymbol{i},\parallel}.\boldsymbol{E}_\parallel$, and $\boldsymbol{J}_{\boldsymbol{i},\perp}.\boldsymbol{E}_\perp$, where $\boldsymbol{J}$ is the current density, $\boldsymbol{E}$ is the electric field, $\boldsymbol{E}'$ is the electric field due to the nonideal terms of Ohm's law, subscripts e and i refer to electrons and ions, respectively, and $\parallel$ and $\perp$ refer to directions parallel and perpendicular to the magnetic field, respectively. The parallel electric field, $\boldsymbol{E}_\parallel$, energizes the inflowing electrons at the separatrices outside the Electron Diffusion Region (EDR). However, most of the power deposition on electrons occurs in the EDR by $\boldsymbol{E}_\parallel$.

The cross-field electron flow and electron pressure gradient in the ion diffusion region (IDR) sets up a perpendicular electric field, $\boldsymbol{E}_\perp$. This $\boldsymbol{E}_\perp$ energizes ions in the regions of IDR frequented by outflowing electrons. The spatial extent of the $\boldsymbol{E}_\perp$ structure driving the ion energization is comparable to the ion gyroradius and the ion acceleration is ballistic like. Energy partition calculation shows 40% of the magnetic energy is converted to particle energy, 67% of which is transferred to ions and 33% to electrons.

References

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