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A magnetospheric energy principle for hydromagnetic stability problems

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A magnetospheric energy principle is formulated to study hydromagnetic stability of a magnetospheric plasma. The magnetospheric plasma is either in a 2-dimensional or 3-dimensional static equilibrium. It is surrounded by lateral perfectly conducting walls and ideal ionospheres in both cases and also by dawn-dusk periodic boundaries in the 2-dimensional case. The 2-dimensional case has a translational symmetry and has no unperturbed magnetic field component in the dawn-dusk direction. Ideal ionospheric boundary conditions are obtained in the lowest order approximation, so that the force operator becomes self-adjoint and a change in the potential energy becomes equal to the change in the fluid energy. Unlike the conventional energy principle for a plasma surrounded by a perfectly conducting wall, field lines thread the ionospheric boundary. Furthermore, the ionospheric boundary is a free boundary. Therefore, a rigid boundary condition is not the only allowable ionospheric boundary condition. There are three ideal ionospheric boundary conditions to satisfy these requirements: insulating, conducting, and rigid boundary conditions. When an unperturbed field-aligned current vanishes, the insulating, conducting, and rigid boundary conditions give interchange, incompressible ballooning, and compressible ballooning modes, respectively. Different characteristics of those three pressure-driven modes are clarified. Existing interchange stability criteria are compared and results of several different numerical stability analyses of ballooning instabilities for different magnetospheric equilibria are discussed in light of the present magnetospheric energy principle. The incompressible ballooning mode is shown to be the most likely substorm onset mechanism among other pressure-driven modes.