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Compressibility and stability criterion of the magnetospheric interchange mode

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Magnetospheric regions of interest are characterized by finite beta plasmas. In such regions, field line curvature influences the dynamics of magnetospheric plasmas by its potentially unstable interaction with plasma pressure gradients. One of these unstable interactions is interchange instability. The possibility of spontaneous large-scale interchange motion of magnetic flux tubes and the plasma contained in them by the interchange instability has been widely discussed as a potentially important mechanism for the redistribution of mass in earth and planetary magnetospheres. The stability criterion of interchange instability for the dipole magnetic field in the low beta plasma limit is well known. On the basis of a magnetospheric energy principle a general stability criterion of interchange instability for an arbitrary high beta magnetospheric plasma bounded by ideal ionospheric boundaries is obtained in this study. The interchange of magnetospheric flux tubes requires the horizontal displacement of magnetic field lines in the ionosphere. According to the magnetospheric energy principle there are two ideal ionospheric boundary conditions allowing the horizontal displacement of magnetic field lines in the ionosphere. One is the horizontally free boundary condition for compressible perturbation and the other is the free boundary condition, which requires that the perturbation is incompressible. Using the geometric optics approximation in the limit of a very large wave number, it is shown that the interchange mode in the magnetospheric plasma bounded by ideal ionospheric boundaries is compressible in the limit of a very large wave number. Then, taking the compressibility into account, the change in the potential energy in the magnetospheric energy principle is calculated for the interchange mode. After minimization of the potential energy and from the condition of positive potential energy, a stability criterion for interchange instability satisfying the horizontally free ionospheric boundary condition is obtained. The difference of the obtained stability criterion for high beta plasma bounded by ionospheric boundaries from the existing stability criterion for high beta plasma on closed field lines is explained in detail. Unlike the stability criterion derived for closed field lines without any boundaries, which is not applicable to the real magnetosphere with ionospheric boundaries, the specific volume used in the stability criterion obtained from the magnetospheric energy principle is defined by line integration from the southern ionosphere to the northern ionosphere and has a definite physical meaning.