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Energy Principle for the Fast Resistive Wall Modes in Tokamaks

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The paper is devoted to theoretical issues in the problem of plasma stability in the toroidal fusion systems with a resistive wall. The basis of the existing stability theory is the standard energy principle [1] derived within the ideal magnetohydrodynamics (MHD) model. A part of that generally accepted approach is the condition that the Poynting vector vanishes at the plasma-facing surface of the toroidal vacuum vessel (simply called wall). In other words, the standard stability theory treats the wall as an ideal conductor preventing the energy flux outside. Ideal plasma with an ideal wall constitute a conservative system. In reality, the system is dissipative at least because of the wall resistivity. In experiments with pulse duration longer than the resistive wall time, this is manifested in excitation of the resistive wall modes (RWMs) in the regions stable according to predictions of the ideal MHD with an ideal wall. Here the energy principle is modified by incorporating the dissipation due to the wall resistivity. Mathematically, the difference from the classical task is that tangential component of the perturbed electric field is now nonzero at the wall. Physically, this means the outward flux of energy (absent in the standard energy principle). This flux can be found by calculating the full energy balance in the outer region or estimated with substitution of proper trial functions. The latter is an element of the variational approaches. Here it is applied by using a proper ansatz for the perturbation in the plasma-wall vacuum gap and in the wall, suitable for the modes faster than conventional RWMs. Accuracy of this method is discussed and asymptotic relations are considered. One of them is the modified energy principle allowing estimates of the growth rates of the fast RWMs. These are, for example, the precursors of more violent and much faster ideal MHD modes. The proposed method is a natural extension of the classical energy principle and contains it in the asymptotic limit. Theoretical and experimental applications of the results are also discussed.

[1] I.B. Bernstein et al., Proc. Roy. Soc. London A 244, 17 (1958).

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