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Axisymmetric modes in tokamak plasmas

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Axisymmetric modes in elongated plasmas are normally associated with a well-known ideal instability resulting in a vertical shift of the whole plasma column. This vertical instability is stabilized by means of passive feedback consisting of eddy currents induced by the plasma motion in a nearby wall and/or in plasma-facing components. When a thin resistive wall is considered, the n=0 mode dispersion relation can be studied analytically with reduced ideal MHD models and is cubic. Under relevant conditions, two roots are oscillatory and weakly damped. These oscillatory modes present Alfvénic frequency and are dependent on plasma elongation and on the relative position of the plasma boundary and of the wall. The third root is unstable and represents the so-called resistive wall mode (RWM) [1].

For the more realistic case of a resistive wall, the third root, i.e. the vertical mode, can grow on the relatively slow resistive wall time scale. Active feedback control is then required for complete stabilization. However, the slow growth is far from ideal-MHD marginal stability on the stable side, i.e., provided that the wall is sufficiently close to the plasma. It is shown that the resistive growth rate can be significantly faster, scaling with fractional powers of wall resistivity, if the wall position satisfies the criterion for ideal-MHD marginal stability, thus posing more stringent conditions for active feedback stabilization [2].

Comparison between the analytic theory of n = 0 vertical displacement modes in magnetically confined plasmas of fusion interest and numerical simulations using the extended-MHD code NIMROD [3] is presented. Agreement between analytic and numerical results is highly satisfactory. Differences are interpreted to be caused mostly by the different wall shape and by the presence of a halo plasma surrounding the hot plasma adopted in NIMROD. A numerical study of Vertical Displacement Oscillatory Modes, dubbed VDOM in [1], is presented. Axisymmetric X-point currents supported by the halo plasma are discussed. This comparison provides a successful benchmark and a useful starting point for future numerical investigations of n = 0 modes using more realistic tokamak geometry and plasma equilibria [4].

The two oscillatory modes can be driven unstable due to their resonant interaction with energetic ions. The fast ion drive, involving MeV ions in present days tokamak experiments such as JET, may overcome dissipative and resistive wall damping, setting an instability threshold, as described in Ref. [5]. The effects of energetic particles are added within the framework of the hybrid kinetic-MHD model. An energetic ion distribution function with $\partial F/\partial E > 0$ is required to drive the instability, achievable with pitch angle anisotropy. or with an isotropic distribution in velocity space with regions of positive slope as function of energy. The latter situation can be achieved by considering losses of fast ions or due to fast ion source modulation [6-7]. Sawtooth oscillations with periods shorter than the fast ion slowing down time may also provide the required modulation [8].

The theory presented here is partly motivated by the observation of saturated n=0 fluctuations reported in [7,9], which were initially interpreted in terms of a saturated n=0 Global Alfvén Eigenmode (GAE). Modeling of recent JET discharges using the NIMROD [7] extended-MHD code will be presented, focusing on mode structure, frequency dependence, and preliminary hybrid kinetic-MHD results. It is early for us to conclude whether, in fact, the mode observed at JET is a VDOM rather than a GAE, nevertheless, we discuss the main points of distinction between GAE and VDOM that may facilitate their experimental identification [10].

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