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Theory of vertical displacements resonant at magnetic divertor X-points

F. Porcelli[1], A. Yolbarsop[2], T. Barberis[1], and R. Fitzpatrick[3]

[1]*Polytechnic University of Turin, 10129 Torino, Italy*
[2]*University of Science and Technology of China, Hefei, Anhui, China*
[3]*Institute for Fusion Studies, University of Texas at Austin, USA*

Vertical displacements are axisymmetric perturbations of a tokamak plasma (with toroidal mode number $n = 0$). They are resonant at the X-point(s) of a magnetic divertor configuration. Mathematically, the resonance condition is $\boldsymbol{B_{eq}} \cdot \nabla\chi = 0$, where χ is a generic axisymmetric perturbation and $\boldsymbol{B_{eq}}$ the equilibrium magnetic field. Because of the X-point resonance, axisymmetric current sheets localized along the separatrix are likely to form. This process, in general terms, is well known to researchers in the fields of astrophysical plasmas as well as fusion plasma experiments. Nevertheless, Refs. [1, 2] are the first articles where the resonant interaction between $n = 0$ modes and the X-point(s) of a tokamak divertor configuration was investigated analytically. Current sheets are observed in numerical simulations of the vertical instability, with advanced numerical codes that can correctly treat the X-point geometry, such as M3D-C[1], NIMROD and JOREK [3]. However, analytic understanding of why these current sheets form, and more importantly, the impact they have on the stability of vertical displacements, was not clarified in those numerical works.

The main result of Refs. [1, 2] is that current sheets along the tokamak divertor separatrix can suppress the vertical instability on the ideal-MHD time scale, thus providing effective passive stabilization even in the absence of a nearby wall. The purpose of this presentation is to review the work of Refs. [1, 2], and to provide additional insight on the mechanism leading to passive stabilization of vertical modes associated with the X-point resonance and with a resistive wall. We will also discuss the possibility that vertical displacements, associated with a branch of the cubic n = 0 dispersion relation, oscillating at the poloidal Alfvén frequency, weakly damped by wall resistivity, can be driven unstable by the resonant interaction with fast ions, as reported in Ref. [4] and possibly observed on JET [5].

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[5] V. G. Kiptily et al, Nucl. Fusion Letter 2021, https://doi.org/10.1088/1741-4326/ac26a2 .