Nonlinear ballooning flux tubes in tokamak geometry

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The nonlinear phase of MHD ballooning modes determines whether they are essentially benign or disruptive. Disruptive or hard limits are produced by ballooning modes across magnetic confinement fusion, for example; as ELMs, some tokamak disruptions [1], and perhaps the LHD Core Density Collapse [2]. This work improves our understanding of how these instabilities develop and might allow us to design plasma profiles such that hard limits are avoided and so improve machine availability and performance.

A nonlinear theory for ballooning flux tubes in large aspect ratio toroidal geometry has been developed [3] which shows that linearly ballooning stable profiles can be unstable to finite amplitude displacements, i.e. they are metastable. We now use the generalized Archimedes' principle developed in [3] to study the nonlinear phase of ballooning flux tubes in realistic tokamak equilibria. We see that saturated filamentary ballooning states are available even when the profile is linearly stable. We qualitatively compare the saturated amplitude of these states to those seen experimentally, for example on KSTAR [4]. We also investigate if this model is applicable to type II ELMs which are thought to be purely ballooning in character [5].

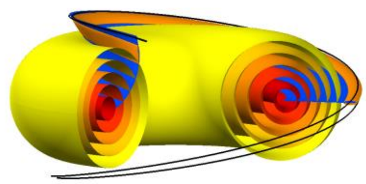

Figure 1: Elliptical (orange) flux tube sliding along (blue) surface S parting surrounding (black) field lines. The tube's displacement is larger on the outboard side of the flux surfaces – the tube balloons. The magnetic shear ($s = rq'/q$) causes the twist and narrowing of the tube on the inside.

This model focuses on the saturation of the ideal MHD ballooning flux tubes which is likely to occur on a fast time scale. However, once this occurs we may see the flux tube break off due to magnetic reconnection and we assess the likely location of this reconnection site.

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