On Feedback Stabilization of the Tokamak Plasma Vertical Instability

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Abstract

For more than a decade the vertical position instability intrinsic to vertically elongated tokamak plasmas has been relatively well understood. Controllers that stabilize this instability have been in routine use at experimental devices since the 1980's. However, most of the analysis of this instability has been restricted to low order approximations, often just one state, from which understanding of the much higher order system has been extrapolated. In this paper, we expand on initial work in [Walker, M.L. (2006)] using a full multivariable model of the plasma vertical instability to provide a rigorous treatment of this problem, which includes the important case in which some of the control coils are superconducting.

We examine two models of the tokamak-and-plasma system, one assuming the plasma has mass, the other assuming zero mass. Although the plasma with mass model is more correct, the massless model is most often used in control analyses. We examine multiple possible systems distinguished by whether there are superconducting control coils in the system, by the magnitude of the instability as defined by a parameter dependent on the equilibrium radial magnetic field structure, and by how well various conductors in the system are coupled to one another. PD feedback is used as the prototype controller to study these models. We find that answers to questions regarding vertical stability, with or without feedback, depend critically on whether the plasma is assumed to have mass or not, but undergo only minor changes with the presence of superconducting coils. Examples are provided in which analyses conducted using a massless plasma model can reach erroneous conclusions. Since the vertical control problem is unfamiliar to many in the general control community, we provide additional tutorial information so that readers may gain insight into the physical origin of the problem.

Key words: Closed-loop stability; Tokamaks; Plasma vertical stabilization; Plasma mass