Nonrigid, Linear Plasma Response Model Based on Perturbed Equilibria for Axisymmetric Tokamak Control Design

A.S. Welander, R.D. Deranian, D.A. Humphreys, J.A. Leuer, M.L. Walker

General Atomics, P.O. Box 85608, San Diego, California 92186-5608 USA,
e-mail: anders.welander@gat.com

Tokamak control design relies on an accurate linear model of the plasma response, which can often dominate the local field variations in regions which affect equilibrium parameters under active feedback control. For example, when fluxes at selected points on the plasma boundary are regulated in DIII-D, the plasma response to a change in a coil current gives rise to a flux change which can be larger than and different from the flux change caused by the coil alone.

In the past, rigid plasma models have been used for linear stability and shape control design. In a rigid model the plasma current profile is considered fixed and moves rigidly in response to control coils to maintain radial and vertical force balance. In a nonrigid model, however, changes in the plasma shape and current profile are taken into account. Such models are expected to be important for future advanced tokamak control design.

The plasma equilibrium is described by the Grad-Shafranov equation, $j_\varphi = Rp' + FF'/\mu_0 R$, where j_φ is the toroidal plasma current and p', FF' are stream functions of the poloidal flux which depend on currents in coils surrounding the plasma and on kinetic and transport characteristics of the plasma. In the absence of kinetic and transport input, one must make a closure assumption to produce a consistent model. One approach to such closure is to make assumptions about the perturbational behavior of the two stream functions based on fundamental physics constraints and supported by empirical observations. We can for example apply the simple assumption that the stream functions are constants with respect to the flux on the magnetic axis so that $p'(\psi-\psi_{axis})$, $FF'(\psi-\psi_{axis})$ are unaffected by plasma perturbations. Other constraints can be applied, for example representing fluid element current conservation. Previous studies have shown that exact flux conservation does not accurately represent the plasma response on control-relevant timescales, and that including the resistive plasma response is important in order to reproduce experimental data (e.g. [1]).

Development of a nonrigid plasma response model for high-accuracy multivariable control design will be described, and comparisons with rigid model predictions will be shown along with validation of model responses against DIII-D experimental data. The linear perturbed plasma response model is calculated rapidly from an existing equilibrium solution without the need for explicit solution of elliptic partial differential equations such as a perturbed Grad-Shafranov equation.

[1] M.L. Walker, D.A. Humphreys, J.R. Ferron, "Control of Plasma Poloidal Shape and Position in the DIII-D Tokamak," Proc. 36th IEEE Conf. on Decision and Control, San Diego, CA (1997) 3703.

*Work supported by the US Department of Energy under DE-FC02-04ER546x98.