Nonlinear Methods for Current Limit Constraint Satisfaction in Tokamak Plasma Shape Control

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The DIII-D tokamak is capable of supporting a wide variety of plasma equilibria because of its relatively large number of coils and their proximity to the plasma. To support its advanced tokamak mission, the DIII-D experimental program continues to push the envelope of this capability, frequently encountering limits imposed by allowable currents in poloidal shaping coils.

With standard DIII-D control algorithms based on approximately one coil controlling each boundary control point, violation of these current constraints is currently dealt with by operator adjustment of control targets and gains between plasma discharges. Accuracy in control is sometimes sacrificed for adherence to current limits in these highly tuned controllers, since violation of a current limit usually causes a premature end to the plasma discharge.

Demands for more precise and stable control have motivated efforts to develop and install advanced multivariable algorithms for control of plasma shape in DIII-D and other devices. Although various linear minimization schemes can be implemented to encourage currents to remain within limits, adherence to these limits cannot be guaranteed by linear methods alone. This limitation has been clearly observed in the process of implementing linear multivariable controllers on DIII-D. There is currently no way to ensure respect of nonlinear current constraints in a multivariable linear controller design and no practical way to manually tune these fully coupled controllers between discharges after installation.

In this paper, we discuss ongoing efforts to provide methods which guarantee currents will not exceed preset limits, and to simultaneously achieve the best obtainable quality of control subject to the current limit constraints. These methods are necessarily nonlinear and include both constrained and unconstrained minimization algorithms, calculated in real time. The methods developed are generalized to the multiple control circuit configurations and to the multiple plasma equilibria supported by DIII-D. Results of experimental implementations will be described.

These methods have important applications in future devices, since the ability to design and build devices with smaller control margins can mean a significant savings in cost of construction and operation.

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