Equilibrium reconstruction improvement via Kalman-filter-based vessel current estimation at DIII-D

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The efficient and safe operation of large fusion devices relies on accurate knowledge of many of the discharge parameters. Unfortunately, the values of several discharge parameters, such as plasma shape and current density distribution, are not directly measured. However, these values can be reconstructed from magnetic field and flux measurements. Equilibrium codes, such as EFIT, calculate the distributions of flux and toroidal current density over the plasma and surrounding vacuum region that best fit, in a least square sense, the external magnetic measurements, and that simultaneously satisfy the MHD equilibrium equation (Grad-Shafranov equation). Once the flux distribution is known, it is possible to reconstruct the plasma boundary for shape control purposes.

The most general approach to the fitting problem treats all toroidal current sources as unknown values. Thus, in addition to the plasma toroidal current, the currents in the external poloidal field (PF) coils can be free parameters and, potentially, the induced currents in the vacuum vessel and support structures can be treated this way as well. There are direct measurements of the external PF coil currents, but these measurements have uncertainties that can be properly accounted for in the least squares fitting procedure by solving for the external currents using the measurements as constraints. A similar procedure could be followed for the vessel currents if they were measurable. Unfortunately, this is not usually the case and vessel currents are often neglected in the fitting procedure.

The important effect of vessel or structure currents has been recognized in many plasma control applications. Kalman filtering theory is used in this work to optimally estimate the current in the tokamak vessel. With the ultimate goal of improving the equilibrium reconstruction for the DIII-D tokamak, the real-time version of the EFIT algorithm is modified to accept the estimated vessel currents. Furthermore, it will be shown that the integration of Kalman filter estimation into the equilibrium reconstruction algorithm provides a new way to validate and refine the plasma dynamic model.