

An efficient MHD equilibrium solver for control oriented transport models

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Successful reproduction of advanced tokamak scenarios in burning plasmas like ITER will strongly rely on sophisticated plasma control systems. Among the novel control physics challenges required to accomplish the control needed for scenario execution, the internal profile regulation plays a fundamental role [1]. The non-linear dynamics involved in current profile control are described by the resistive magnetic diffusion equation (MDE) expressed in flux coordinates. These coordinates are constructed out from the magnetic geometry imposed by the MHD plasma equilibrium condition. During a tokamak discharge the plasma equilibrium, its internal profiles and the magnetic geometry change, therefore, the flux coordinates should be updated during this evolution. However, the equilibrium is held fixed and the update of the flux coordinates is not yet performed by the newest control-oriented transport codes [2,3].

This simplification is made for practical reasons. On one hand, the solution of the Grad-Shafranov equation for general axisymmetric equilibria involves two nested loops (one inner loop to treat the non-linearity and one outer loop to treat the eigenvalue nature of this equation [4]) that make standard equilibrium solvers unacceptably expensive and poorly convergent. On the other hand, the resulting inconsistency is, in many cases, not severe and effective feedback control of the current profile has been achieved for some relevant scenarios [2]. Despite this partial success, an efficient method to couple the equilibrium problem with the MDE solver in control-oriented transport codes would represent a significant improvement. With such self-consistent approach, more accurate feedback controllers could be designed, better feedforward controllers for scenario planning would be available and a fast and reliable control-oriented predictive simulation tool could be developed.

In this work, a new flux mapping method that allows a rapid estimation of the RHS of the Grad-Shafranov equation, including the eigenvalue, is introduced. This method significantly accelerates the outer loop and improves the convergence properties of the solver. In particular, equilibria with arbitrary prescribed safety factor and pressure profiles can be obtained with few outer iterations (less than five for low-beta plasmas). Moreover, the change in the equilibrium and the magnetic geometry during a control-oriented transport simulation can be recovered without the outer loop, using only few Newton iterations in the inner loop to treat the non-linearity. We show that the new mapping method can also be used to compute the internal plasma equilibrium using only the total plasma current, the shape of the separatrix and the spatial profile of the field line pitch angle. This approach differs from the traditional equilibrium reconstruction method (which uses the pitch angle information as a constraint [5]) and have many potential applications in the design of control systems requiring spatial information of the plasma parameters.

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Primary authors: GARCIA-MARTINEZ, Pablo (CONICET - Centro Atomico Bariloche); Mr MONTES, Pablo (CONICET - UNCor); FARENGO, Ricardo (Comision Nacional de Energia Atomica)

Presenter: GARCIA-MARTINEZ, Pablo (CONICET - Centro Atomico Bariloche)

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