IDENTIFICATION OF PLASMA EQUILIBRIUM IN A TOKAMAK.

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The problem of the equilibrium of a plasma in a Tokamak is a free boundary problem, the plasma boundary being defined either by its contact with a limiter or as being a magnetic separatrix (hyperbolic line with an X-point). The equilibrium equation inside the plasma, in an axisymmetric configuration, is a semi-linear elliptic p.d.e., called Grad-Shafranov equation. The right-hand side of this equation is a non-linear source, which represents the toroidal component of the plasma current density. The aim of this work is to perform the real-time identification of this non-linearity from experimental measurements, such as magnetic measurements (Cauchy boundary conditions) or polarimetric measurements (integrals of the magnetic field over several chords)..

A C++ software, called EQUINOX [BBJ],[BBJS] has been developed in collaboration with the Fusion Department at Cadarache, and has been implemented for JET (Joint European Torus) and for TORE SUPRA (the CEA-EURATOM Tokamak at Cadarache). Only a few number of degrees of freedom can be identified from the magnetic measurements (Dirichlet and Neumann boundary conditions) on the vacuum vessel. A better identification of the current profile is performed by using polarimetric measurements, which give the integrals of the magnetic field over several chords. This considerably improves the identification of the non-linearities in circular configurations, such as TORE SUPRA, where the identification is the most difficult and also in elongated configurations such as JET. The main problem was to achieve this within a few ms, so as to be able to control in real time the current profile.

The main challenge here is to find numerical algorithms that enable to solve the problem in real time. The major ideas are: computation of the inverse of the finite element stiffness matrix once for ever, pre-computation of all the elements that are not modified by the non-linearities, Picard iterations for these non-linearities, reduction in small dimension basis, least-square resolution by normal equations and optimal organization of the software so as to save time at each stage of the inversion. With all these techniques, it was possible to follow the quasi-static evolution of the plasma equilibrium, either in TORE SUPRA or JET configurations, with free boundaries defined either by limiter contact or with an X-point. It was also possible to simulate ITER configurations.

References:

[BBJ] J. Blum, K. Bosak, E. Joffrin: New applications of Equinox code for real-time plasma equilibrium and profile reconstruction for tokamaks, 12th ICPP International Congress on plasma physics, Nice, 2004

[BBJS] Bosak K., Blum J., Joffrin E., Sartori F.: Real-time plasma magnetic equilibrium reconstruction for tokamaks, EPS Conference on plasma physics, Saint-Petersbourg, 2003.