CEA / DSM / Institut de Recherche sur la Fusion par confinement Magnétique

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Abstract

, plasma performances in term of internal stored kinetic energy are growing year after plasma position is a key issue in order to **avoid** the device. Such a control is essential when nas have to be performed as on the Tore Supra by the plasma can be localized using magnetic outside the plasma. The plasma boundary can led on real time in less than a few milliseconds.

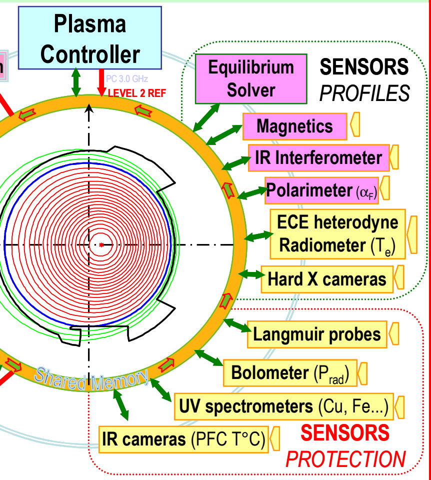
ation on the **current distribution inside the** alculation must be performed. The **2D Grad-** g the force balance between kinetic pressure nmetric toroidal geometry must be solved. Such lly implemented in C++ and installed on Tore enough to enable a **real time equilibrium**

rements are no longer sufficient to constrain nformation on current distribution inside the measurements must be introduced as **external** ts of constraints have been implemented:

metry measurement giving line integrated

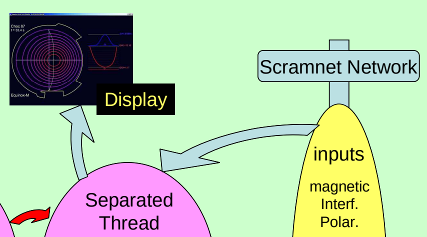
easures Faraday rotation effect provides magnetic field.

ne Implementation

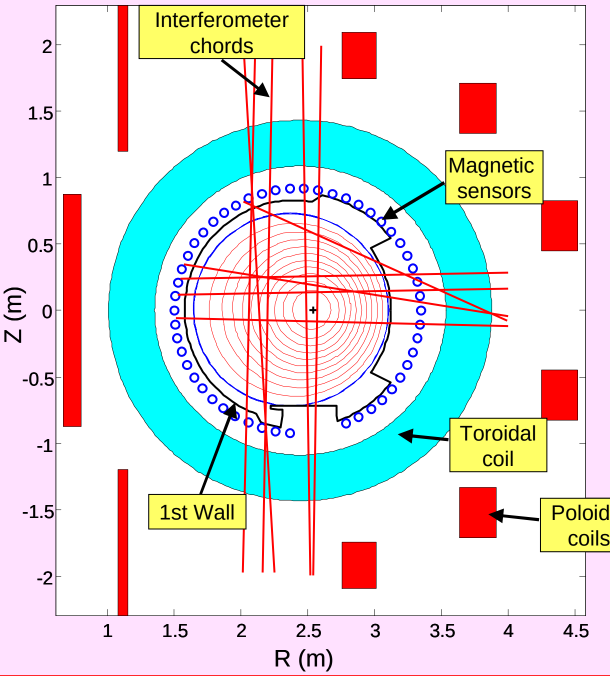


nGL library for RT interface
r Hyper Threading)
mother card,
card

ring SCRAMNet® (Systran corp.) at 150MHz
Synchronization with the timing sysstem:
PCI-6601 & PCI-6533 cards.
rk: SYSTRAN Corp. PCI 150+ card



Poloidal View of Tore Supra Tokamak & Used Measure



Magnetic measurements:
✪ 51 pick-up coils: local B_θ
✪ 6 toroidal flux loops

Integration of inductiv
✪ 51 pick-up coils: loca
✪ 2 poloidal flux loops

Infra-Red interferometry measurements: 10 chor
✎ Modification of the optical length by the plasma
✎ Used in association with polarimetry measuremen

$$\int_{C_i} n_e \, dl = \beta_i.$$

Infra-Red polarimetry measurements: 10 chords
✎ Faraday rotation effect of a polarized IR laser b
✎ Measure the magnetic field component parallel t

$$\int_{C_i} \frac{n_e}{r}\frac{\partial \psi}{\partial n} dl = \alpha_i.$$

Tore Supra Mesh used for
Real Time Equinox solver
412 nodes, 762 P1 triangle elements,
60 nodes on boundary
(**Black**: TS first wall)
Boundary mesh is chosen to be closed to
magnetic sensor localisation.

2D Grad-Shafranov Equation

Grad-Shafranov equation:
✎ Axisymmetric geometry ⇒ **2D equation** (r and z cylindrical coordinates)
✎ balance between **Lorentz force j × B** and the **∇p force due to pressure gradient**
& quasi-static form of Maxwell equations

$$-\Delta^*\psi = rp'(\psi) + \frac{1}{\mu_0 r}(ff')(\psi) \quad \text{where} \quad \Delta^*. = \frac{\partial}{\partial r}\left(\frac{1}{\mu_0 r}\frac{\partial .}{\partial r}\right) + \frac{\partial}{\partial z}\left(\frac{1}{\mu_0 r}\frac{\partial .}{\partial z}\right).$$

- ψ(r, z) is the poloidal magnetic flux function,
- r and z cylindrical coordinates,
- μ_0 is the magnetic permeability
- p' pressure gradient distribution
- f = r B_ϕ and f' its derivative
- prime derivative is with respect to ψ

The right hand side (non linear) of GS equation represents the toroidal component j_φ of the plasma current density which is governed by *p'*, *f* and *f'* functions (null outside the plasma).

Solving GS equation with **given boundary conditions** from magnetic measurements is a **free boundary problem** in which the plasma boundary is free to evolve. This is an **ill-posed problem** which needs a dedicated algorithm to be solved.

GS equation is solved numerically using **finite element method.**

Ω domain of the vacuum vessel: decomposed in P1 triangle mesh. ∂Ω its boundary
Ω_p plasma boundary $\Omega_p = \{\mathbf{x} \in \Omega, \ \psi(\mathbf{x}) \geq \psi_b\}$ where $\psi_b = \max_D \psi$ (limiter configuration).

J. Blum et al, ICIPE 2008: 6th Int. Conf. on Inverse Problems in Engineering, Dourdan : France (2008)

Iterative

❶ **Starting guessing** (ψ, Ω time step.

❷ **Optimization step**: com **ff'(ψ^n)$^{n+1}$** functions using a le procedure and including **Neu as external constraints.** The account the accuracy of each **ff' functions are decompose** polynomials,...) which reduces free parameters (typically 5

❸ **Direct problem step**: s **ψ^{n+1} and Ω$_p^{n+1}$ using the p'^{n}** previously calculated and Dir

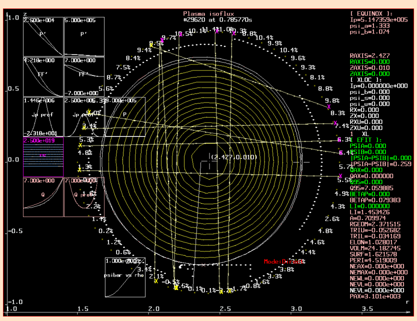
❹ **Check for convergenc**

Tikhonov regularizati function (ill-p

Boundary conditions &
From magnetics:
- toroidal flux loops ⇒ Dirich
- pick-up coils ⇒ Neumann c

Other Constraints: Int

Real Time & Off-Line Results



Display variation to magnetic measurements, and comparison with EFIT equilibrium solver

✪ Microsoft Visual C++ compiler. Also available for Linux (GNU gcc, Kai KCC) and SunOS (DEC CXX and GNU gcc-g++)

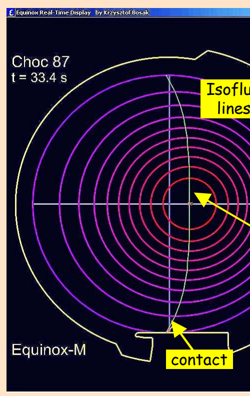
✪ Interface with Tore Supra Database: MATLAB® script

✪ Standalone interface for GIF or EPS picture generation.

✪ Capability for comparing results with other equilibrium solvers (EFIT), and RT results

2 types of Off-line Display (GIF/EPS picture)

Real-Time Equino



Real Time Display using O