Real-time magnetic equilibrium enhancements

JANET : Just ANother Equilibrium code for Tokamaks


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A data acquisition system for real-time magnetic equilibrium reconstruction on ASDEX Upgrade and its application to NTM stabilization experiments L.Giannone, M.Reich et. al, Fusion Eng. Des., 88, 3299, 2013
Ferromagnetic tiles

Two rows of low cost, low activation, neutron resistant ferromagnetic material (P92) EUROFER foreseen for DEMO

Expected perturbations to magnetic probes near these tiles need to be taken into account for magnetic equilibria

Boundary condition $\frac{B_{//i}}{\mu_{eff}} = B_{//e}$

Model magnetisation by surface currents on tile
Magnetic probe signals due to surface currents on ferromagnetic tiles for calibration discharge with excitation of individual poloidal field coils

Difference of calculated and measured probe signals indicate that modelling of tiles is successful for calibration discharge with excitation of individual poloidal field coils
Ferromagnetic tile calculations

\[ \sigma_M = \frac{1}{2} \frac{\mu_{\text{eff}} + 1}{\mu_{\text{eff}} - 1} I + \frac{M}{M_{ij}} \]

Benchmarked with FEM models (I.Zammuto)
Colo perturbations due to ELM’s
Probe compensation of Colo current

Difference in calculated and measured probe signal without accounting for low pass filtering of vacuum vessel

Difference in calculated and measured probe signal when accounting for low pass filtering of vacuum vessel
Equilibrium comparison

EQH (64x128) offline (CLISTE)
EQR (33x65) real-time (JANET)

Ip = 0.8 MA, PNBI = 12.5 MW, PECRH = 2.6 MW  
Ip = 1.0 MA, PNBI = 2.6 MW, PECRH = 2.4 MW
Comparison of time evolution of offline EQH \((q_0,q_{50})\) and real-time EQR \(q(r)\) profiles show that the offline \(q_0\) can significantly differ from 1.

Internal constraints from polarimetery or MSE in addition to the magnetic probe measurements are absolutely necessary to fix the value of \(q(0)\).

Now 6 \(P'\) and 6 \(FF'\) coefficients with regularisation for basis functions -> lookup table
30 pairs of inner and outer magnetic probes
18 loop voltages external to vessel
\[ j(vessel) \text{ measurements} \]

\[ \rho_{SS304} = 7.2 \times 10^{-7} \Omega m \]

\[ \rho_{MESS} = 3 \times 10^{-6} \Omega m \]

\[ \mu_0 j \omega L = (B_i - B_e) L \]
j(vessel) from ULa?

- reduce fitting errors in current ramp
Equilibrium reconstruction of plasma profiles based on soft x-ray imaging in DIII-D

Soft x-ray tomography for real-time applications (Tore Supra)
SXR tomography and magnetic axis

![Graph showing R(m) and Z(m) over time](image)

- SSZ/R2_3
- IDE/Rmag
- EQH/Rmag
- EQR/Rmag

- SSZ/Z2_3
- IDE/Zmag
- EQH/Zmag
- EQR/Zmag

Time (s)
T. Odstrcil (SSZ tomography shot files), G. Conway (cview)

Polarimeter constraints

![Graphs showing time evolution of various parameters](image)

- **$n_L$ (m²)**
- **Cycle time (s)**
- **Angle (rad)**

Parameters:
- H1
- H2
- H0
- H4
- H5

Time (s): 0 to 8
Density profile

Offline and Real-time density profiles over time.
Summary

★ Real-time magnetic equilibria routinely available with 2 ms cycle time for NTM stabilisation and disruption avoidance experiments

★ Using 6 spline basis functions for P´ and FF´

★ q(0) = 1 constraint

★ Low pass filter applied to Col to account for vacuum vessel shielding

★ Ferromagnetic tiles included in RT equilibria

★ Vessel currents/polarimeter to be included in RT equilibria

★ Soft x-ray tomography and equilibrium comparison started
rtEFIT algorithm

Find set of coefficients for (spline) current basis functions giving best fit to probe measurements

Real time equilibrium reconstruction for tokamak discharge control
J.R.Ferron et. al, Nucl. Fusion, 38, 1055, 1998
Col coil currents

Transfer function measured by recording probe response at 10, 20, 40 and 80 Hz