Integrated equilibrium reconstruction and MHD stability analysis of tokamak plasmas in the EU-IM platform

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I – Introduction

The performance and operational limits of present and future Tokamak plasmas are influenced by the equilibrium profiles, shape and position e.g. vertical position stability in strongly shaped plasmas or onset of disruptive instabilities driven by profile gradients. Free boundary plasma equilibrium profiles can have a strong effect on the interpretation of all physical phenomena occurring in the plasma e.g. core/edge MHD stability characterization, plasma transport and auxiliary heating. It is thus a fundamental task to determine the plasma equilibrium using as many available input experimental data e.g. magnetic diagnostics (magnetic flux and poloidal magnetic field), density and temperature diagnostics and polarimetry diagnostics. In the framework of the EUROfusion Work Package on Code Development for Integrated Modelling, a scientific Kepler [1] workflow for the reconstruction of Tokamak plasma equilibrium was developed (Figure 1). It includes consolidated reconstruction codes such as EQUAL [2], CLISTE [3], EQUINOX [4] and post-processing error bar estimator SDSS [5], all using the same physics and machine data ontology and methods for accessing the data used in the European Integrated Modelling (EU-IM) framework [6]. Presently implemented modules (*actors*) are interfaced to “data bundles” e.g. magnetic sensors, Thomson scattering diagnostics as well as poloidal field coil data, are packed into a “machine bundle”, to facilitate the data exchange in the workflow through self-consistent datasets. The reconstruction codes feature polynomial or spline (natural or B-spline) representation for the profiles and non-uniform spatially distributed knots for the equilibrium regularisations are implemented. Equilibrium reconstructions relying on magnetics data only (magnetic diagnostic, PF/TF coils and iron core) or with added internal data (motional Stark effect, polarimetry or pressure) may be performed.

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* See http://www.euro-fusionscipub.org/eu-im
& See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia

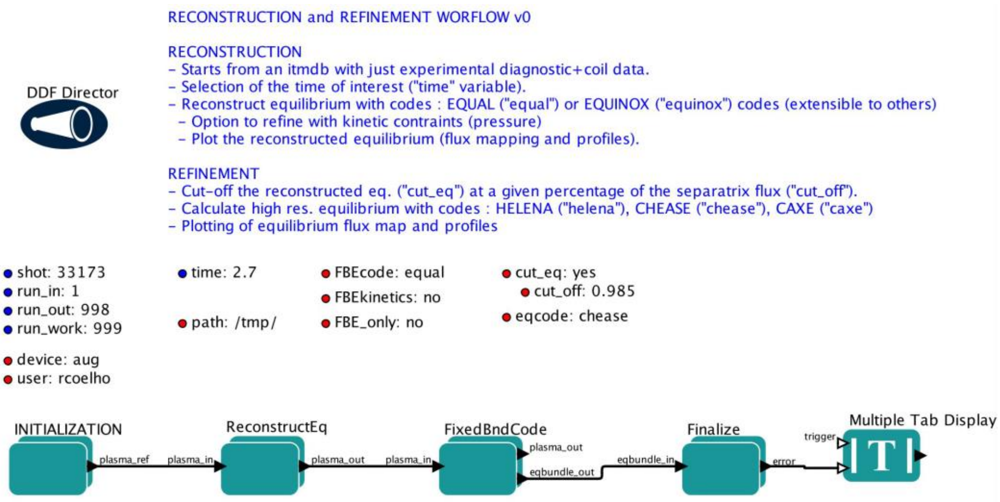

Figure 1 – Kepler workflow for equilibrium reconstruction of tokamak discharges. An optional post-processing module FixBndCode[7] for the calculation of the high resolution equilibrium is shown.

For pedestal top/edge pressure profile assisted reconstructions, pre-processing of the experimental density and temperature data presently includes a median filter and time average around the time of interest, mapped to the flux coordinates obtained for that time in the previous (magnetics only) reconstruction. Ion density is assumed to be proportional to electron density and fast particle density is assumed negligible.

II – Motional Stark Effect assisted reconstructions

A JET hybrid discharge (#89140) was considered to highlight the influence of internal MSE data on the equilibrium reconstructions, with a plasma current and toroidal magnetic field of 1.4MA and 1.75T respectively, 12.5MW of NBI and 1.9MW of ICRH ([49-52s]). EQUAL and EQUINOX results using magnetics only are shown in Figure 2 for t=47.45s with CHAIN1 EFIT used for comparison. Good agreement in the plasma boundary (<1cm for EQUAL, <2cm for EQUINOX at outer midplane) and divertor strike points (<2.5cm) is found and fitting errors in the magnetics are below the experimental 5mT error. Even with magnetics only, the regularisations in EQUAL permit some (insufficient in view of the ELMy discharge) traces for a pedestal at the edge. The safety factor **q** evidences the lack of fidelity of the automated EFIT reconstruction i.e. **q**(0)>1 throughout despite the sawtoothing character of the discharge. Inclusion of MSE data shows a clear improvement on the overall agreement in the q(s) profile (<5% difference in q(0) among the 3 codes) as shown in Figure 3. Differences in the regularisations and/or weighting on sensors might explain the deterioration in the agreement on plasma boundary and magnetic axis location.

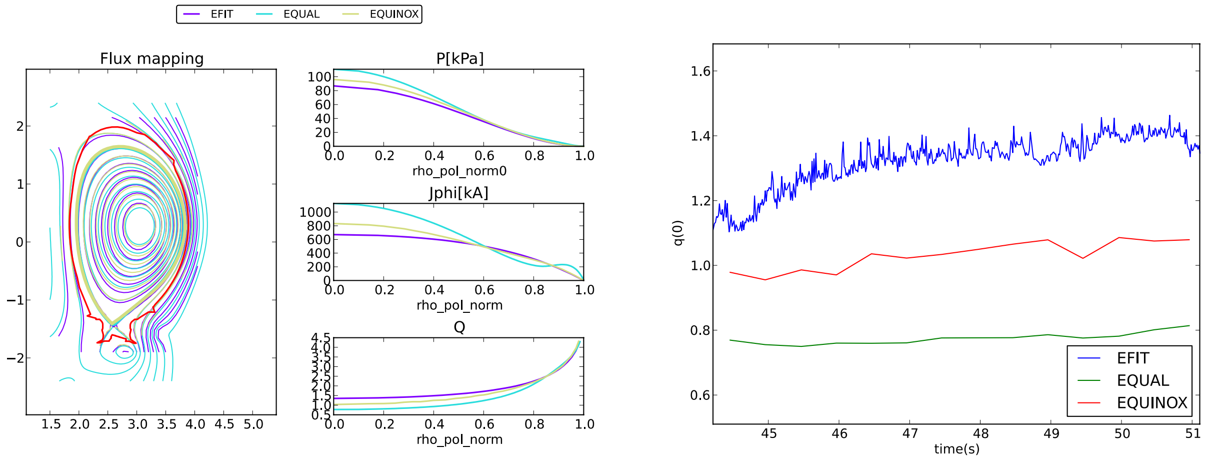

Figure 2 – Magnetics only reconstruction using EQUAL and EQUINOX and EFIT for comparison (rho_pol_norm - squared root of the normalised poloidal flux) for JET #89140 at t=47.45s.

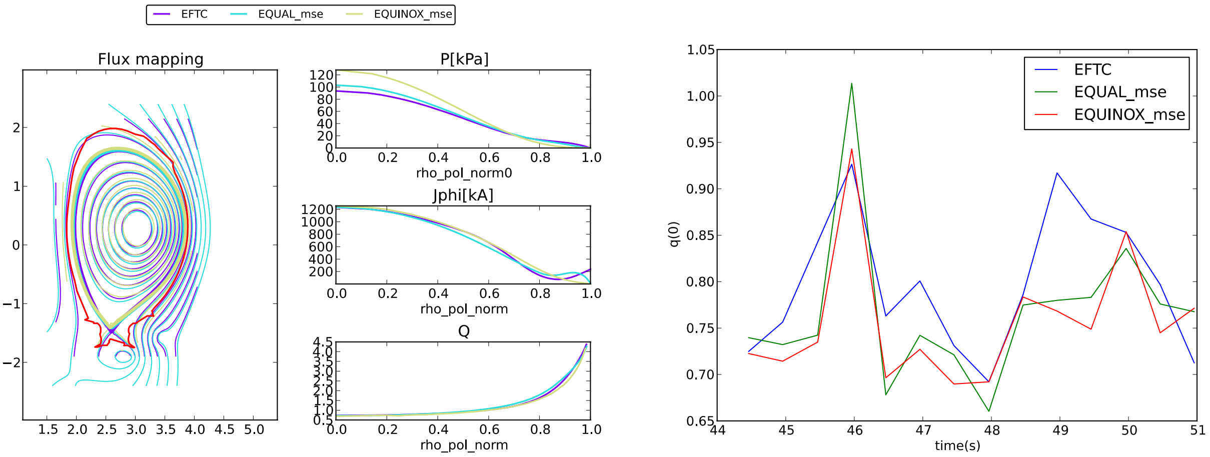

Figure 3 – Magnetics and MSE reconstruction for JET #89140 at t=47.45s. The EFTC run relaxes the J_{sep}=0 constraint. Location and weights of regularisation knots not the same for the 3 codes.

III – Plasma pressure assisted reconstructions

For pressure assisted reconstruction, an AUG ELM-y discharge (#33173) was taken as example, at t=2.7s, characterized by Ip=1MA, B_T=2.46T and total heating power (NBI+ECRH) of ~12MW. The CLISTE code, fine-tuned to AUG plasmas, is used as a reference. For magnetics only reconstructions (see Figure 4), EQUAL and EQUINOX yield similar plasma geometry (<1cm on outer midplane radius, <2 cm separation of X-point and <2cm separation on strike points) to CLISTE but are challenged on the q(s) on axis and showing little evidence of a pressure pedestal. The associated fitted edge pressure profile from the diagnostic data (Ni=Ne is assumed) is also shown in Figure 4. The pressure constraint closes the gap between the profiles obtained by the three codes (see Figure 5) and also reduces the average fit error of the magnetic sensor data for EQUAL and CLISTE (EQUINOX solution in vacuum based on a toroidal harmonic expansion fit to magnetic data, is insensitive to internal constraints).

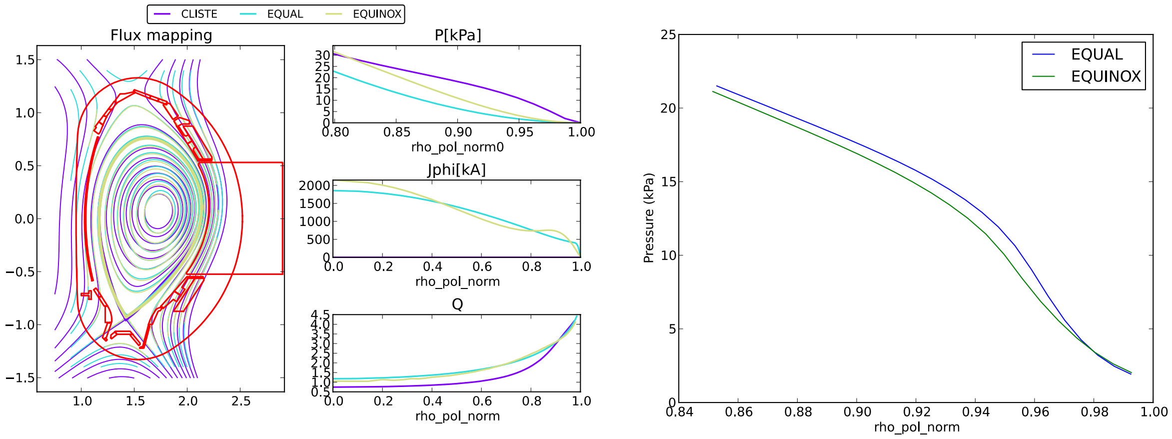

Figure 4 – Magnetics only reconstruction on AUG discharge #33173 at t=2.7s. Edge detail on pressure profile is shown (left). The pressure profile mapped to EQUAL and EQUINOX is also shown.

The pressure profile fed to CLISTE, based on averaged data 2ms before ELMs occurring in a 200ms period centred on t=2.7s, yields a slightly higher pedestal pressure (~17kPa).

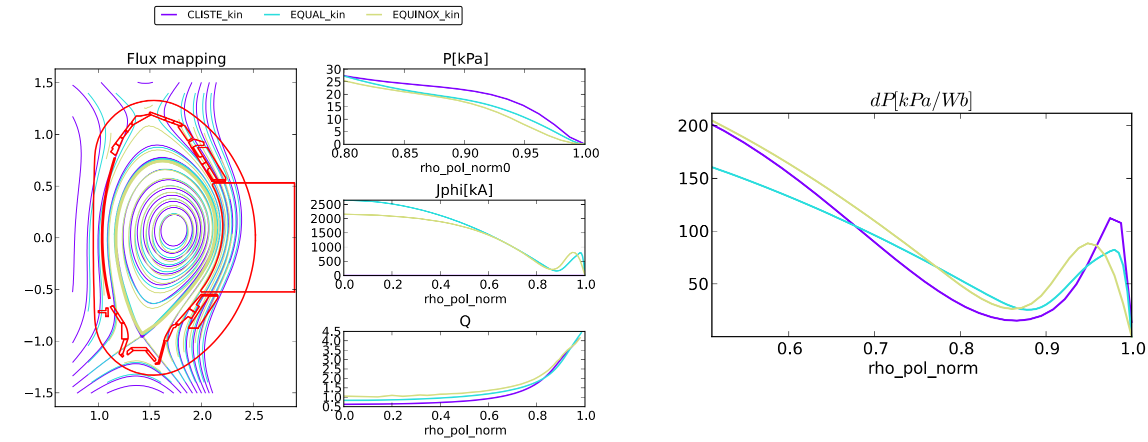

Figure 5 – Magnetics and pressure assisted reconstruction on AUG discharge #33173 at t=2.7s. Detail on the pressure gradient close to the edge is also shown (right).

IV – Conclusions

Results of a EU-IM workflow for equilibrium reconstruction applied to a JET and AUG discharge were shown. Magnetic, polarimetry and kinetic constraints are implemented and evidence an improvement in the fitted results although some differences to reference code suites in JET/AUG persist (fine-tuning options or data used may apply there).

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References
[1] https://kepler-project.org/; [2] W. Zwingmann, Nucl. Fusion **43** (2003) 842 ; [3] P. J. McCarthy, Phys. Plasmas **6**, 3554 (1999); [4] B. Faugeras et al., Plasma Phys. Control Fusion **56** (2014) ; [5] R. Coelho et al, Fusion Sci. Technol. **69**, 611 (2016); [6] F. Imbeaux et al Computer Physics Communications **181**, 987 (2010); [7] R. Coelho et al., “Scientific workflows for MHD stability chain analysis of tokamak plasmas”, 42th EPS Conf., Lisbon 2015