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CONSISTENCY OF CURRENT PROFILE RECOVERY ON JET USING TRANSP AND EFIT CODES

D.J. Kelliher[*], P.J. McCarthy[*], Y. Baranov, J.P. Christiansen[+], N.C. Hawkes, B.C. Stratton[#] , P.M. Stubberfield

UKAEA Culham Science Centre, Abingdon, Oxon OX14 3EA, UK.
[*]*Physics Department, University College Cork, Association Euratom-DCU, Cork, Ireland.*
[#]*Princeton Plasma Physics Laboratory, Princeton, NJ, 08543, USA.*
[+]*Euratom/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK.*

1. Introduction

Accurate determination of the current profile is critical to understanding the physics of advanced tokamaks [1]. The current profiles calculated by the free-boundary equilibrium code EFIT constrained internally by the Motional Stark Effect pitch-angle measurements and/or the pressure profile produced by the transport analysis code TRANSP are compared. The analysis was carried out on an optimised shear discharge (#47413). The current profile is also calculated by TRANSP using the magnetic diffusion equation.

2. TRANSP current profile

TRANSP calculates the inductive component of the plasma current using the magnetic diffusion equation. Equilibrium flux surfaces are first calculated by EFIT based on external magnetic measurements only [2]. The magnetic diffusion equation is derived from a combination of Maxwell's equations. In axisymmetric flux surface geometry, Faraday's equation can be expressed as follows:

$$\frac{\partial}{\partial\rho}\left[\frac{\left\langle \underline{E}.\underline{B}\right\rangle_V}{RB_T\left\langle 1/R^2\right\rangle_V}\right]=\frac{\partial}{\partial t}\left(\frac{\partial\psi}{\partial\rho}\right) \qquad (1)$$

The terms within the angle brackets are volume averaged between flux surfaces. This equation characterises the diffusion of the flux surfaces in the plasma towards the magnetic axis. Ohm's law can be written as follows:

$$\left\langle \underline{E}.\underline{B}\right\rangle_V=\eta_{//}\left[\left\langle \underline{J}.\underline{B}\right\rangle_V-\left\langle \underline{J}.\underline{B}\right\rangle_V^{NI}\right] \qquad (2)$$

The $\left\langle \underline{J}.\underline{B}\right\rangle^{NI}$ term is the non-inductive contribution to the current density, i.e. bootstrap and beam-driven currents, which is calculated separately. TRANSP calculates the resistivity $\eta_{//}\propto Z_{eff}T_e^{-1.5}$ using the LIDAR electron temperature measurements and Zeff derived from analysis of Charge Exchange Spectroscopy. Neoclassical resistivity was used in the analysis. Using (1) and (2), TRANSP calculates the ohmic current profile for the following timestep.

3. MSE diagnostic

A Lorentz electric field is induced on an atom moving across a magnetic field causing spectral line splitting and linear polarisation of the emitted radiation [3]. The MSE diagnostic measures polarised light emission from neutral heating beams, providing measurements of local magnetic pitch angle γ. Pitch-Angle measurements in the plasma allow fine structure in the current profile to be resolved. The JET MSE diagnostic has 25 channels. The design of the neutral beam injection system complicates the operation of the diagnostic [4]. Some outboard channels are ignored due to limitations of the viewing geometry of the MSE diagnostic. The radial electric field can affect the interpretation of the MSE measurements [5]. This correction is significant in plasmas with large rotation velocities or pressure gradients. A technique has been developed to measure E_r and thus improve the MSE pitch-angle measurement [6].

4. EFIT current profile

Assuming ideal MHD equilibrium, the force balance equation can be written as follows:

$$J_\varphi = R\frac{dp}{d\Psi} + R^{-1}\mu_0^{-1}F\frac{dF}{d\psi} \qquad (3)$$

The scalar function F is related to the toroidal magnetic field, F= RB_ϕ. Substituting for $J_\varphi = -R^{-1}\mu_0^{-1}\Delta^*\psi$ into the LHS of (3) gives the Grad-Shafranov equation. EFIT solves the Grad-Shafranov equation by iteratively adjusting a modest number of free parameters characterising the toroidal current density profile, J_ϕ. These free parameters are chosen so as to minimise the sum of squared deviations between a chosen set of experimental data and those predicted by EFIT. Without MSE or other internal constraints, EFIT can only be relied upon to identify global moments of the current profile such as $\beta_{poloidal}$[7]. In the following, J_ϕ is parameterised in terms of splines to accommodate the inclusion of MSE pitch-angle measurements and TRANSP pressure profile.

5. TRANSP-EFIT analysis

The TRANSP analysis was performed on shot 47413 from 42.0 s to 49.5 s. The time point 46.0 s was then selected for further analysis by EFIT with additional constraints from the MSE pitch angle data. MSE data was not included in the TRANSP analysis. The current profile obtained when EFIT is constrained by the MSE data and/or the TRANSP pressure profile was then compared. This shot is an optimised shear discharge with, at the time point selected, 11MW of neutral beam and 7.0 MW of ICRH power. The MSE data has been corrected for radial electric [8] field.

The TRANSP calculated current profile depends on the resistivity. Figures 1 and 2 indicate that the data supplied to TRANSP is reliable. Figure 1 shows that the neutrons calculated by TRANSP are in reasonable agreement with those measured by the neutron monitors. The loop voltage calculated also conforms to that measured (Figure 2). It can thus be supposed that the electron temperature and Zeff measured are reasonably accurate. Therefore, it can be assumed that the resistivity is based on sound experimental data.

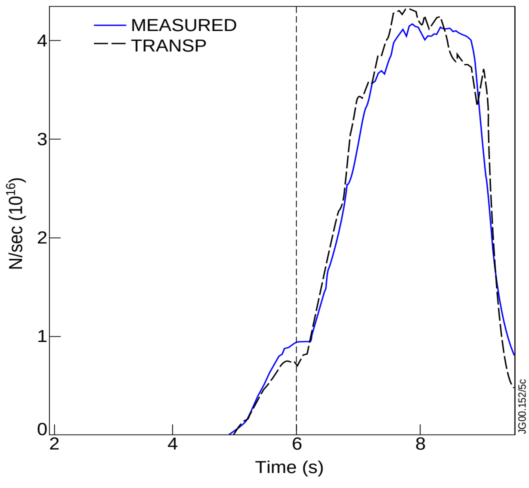


Figure 1: Neutron Rate

EFIT was run with MSE data only and with both the TRANSP pressure profile and MSE data. The current profile was parameterised by a nine knot spline model. The fit to the MSE pitch-angle measurements in both cases is shown in figure 3. The MSE channels beyond R=3.65 were not used in the fit. The RMS deviation from the MSE data when EFIT was run without pressure profile was 0.39 degrees; with the pressure profile the RMS deviation was 0.42 degrees. EFIT is able to fit to the MSE data in both cases as it is free to choose FF’ even if P’ is prescribed.

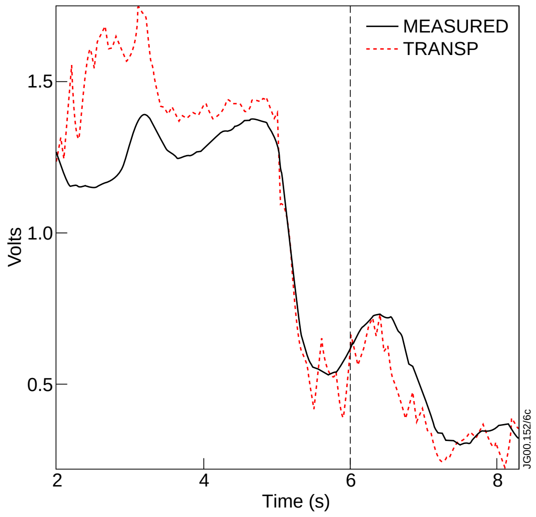
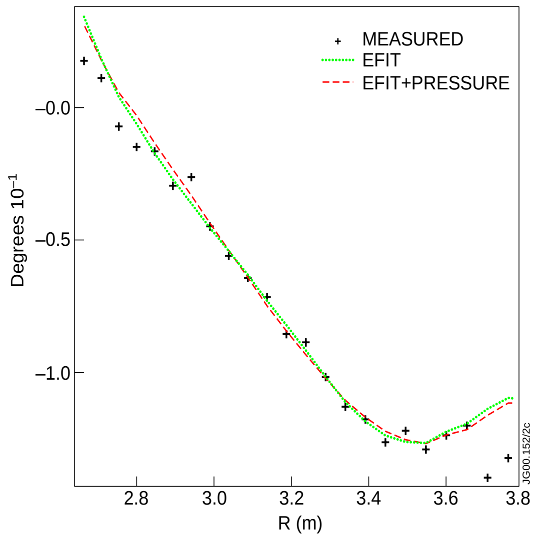
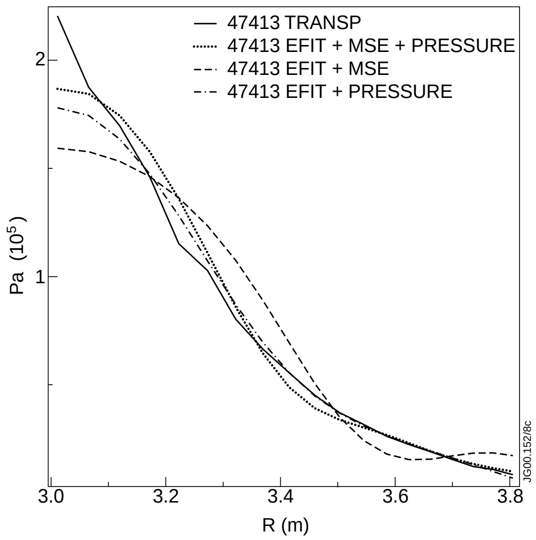


Figure 2: Loop Voltage





6. Comparison of Current profiles

The current density profile calculated by TRANSP, as described in section 2, is shown in figure 5. It has been found that the parallel electric resistivity is in good agreement with the predictions of neoclassical theory [9]. Figure 5 indicates that the current density calculated assuming neoclassical resistivity is consistent with that obtained from EFIT with MSE data and pressure profile as constraints. However, the hollow current profile obtained by EFIT is not reproduced by the TRANSP magnetic diffusion equation. Unlike EFIT, the

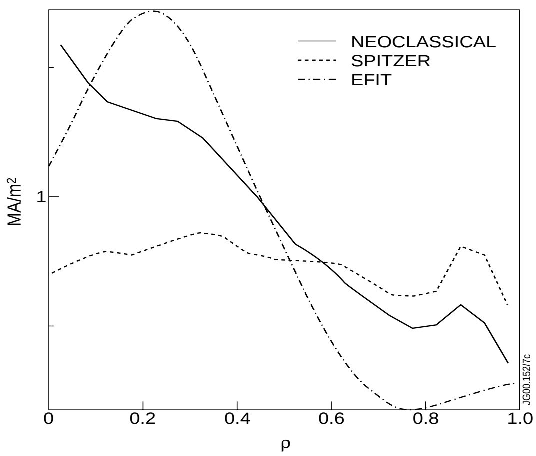


Figure 5: Current density profile from TRANSP and EFIT

MSE pitch-angle data is not included in the TRANSP analysis.
TRANSP utilises a Monte-Carlo technique to track the fast particles in the plasma. This introduces noise that is apparent in the pressure profile calculated by TRANSP (figure 4).

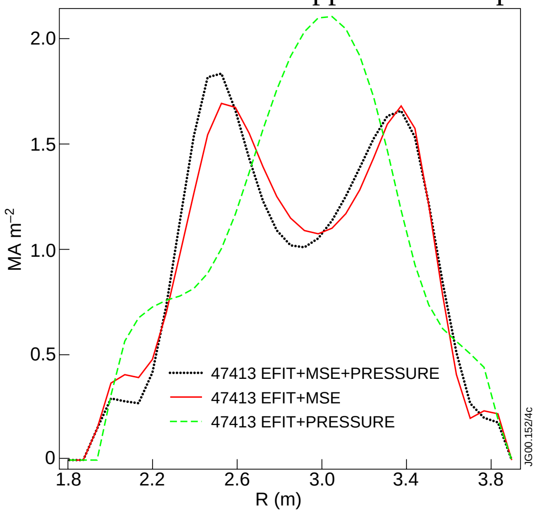


Figure 6: EFIT current density profiles

For the time point analysed, EFIT internally constrained by the MSE data produces a hollow current profile. On the other hand, EFIT internally constrained by the TRANSP pressure profile (i.e. ignoring the MSE data) produces a peaked current profile. When EFIT is run both with MSE data and the TRANSP pressure profile a hollow current profile results while the fit to the TRANSP pressure profile is quite reasonable (see figure 4).

7. Conclusions

From figure 3,4 and 6 it is apparent that the TRANSP pressure profile is consistent with the EFIT equilibrium constrained by MSE data. With TRANSP pressure alone as a constraint, the EFIT current density profile is peaked. This may be due to the assumption of isotropy in the pressure profile [10]. Furthermore, the pressure profile calculated by TRANSP, including the Monte-Carlo simulated fast-ion component is very peaked. On the other hand, with the inclusion of MSE data as internal constraints, the EFIT current density profile is hollow. In future work, it is planned to incorporate MSE data into the EFIT stage of the TRANSP-EFIT analysis.

8. References

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