Test of current ramp modelling for AT regimes in JET

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For the first time, measurements of the q-profile have been made one second after the time of plasma initiation (t_{init}) in the JET advanced tokamak (AT) regime, the data being obtained at both 2.0T and 2.7T using the motional Stark effect (MSE) system [1]. Multiple EFIT reconstructions within the uncertainties on the MSE data have produced q-profiles with error bars (figure 1) showing shear reversal inside (r/a) ~0.66/0.7 with a region of very low current density in the plasma centre. This demonstrates that deep shear reversal is generated in large volume JET plasmas by a plasma initiation with an early current ramp phase without the need for non-inductive current drive. The magnetic shear is more negative and the negative shear region is larger at higher magnetic field when the same current waveform is used, possibly linked with the observed stronger n=1 MHD activity at the lower values of q-cylindrical.

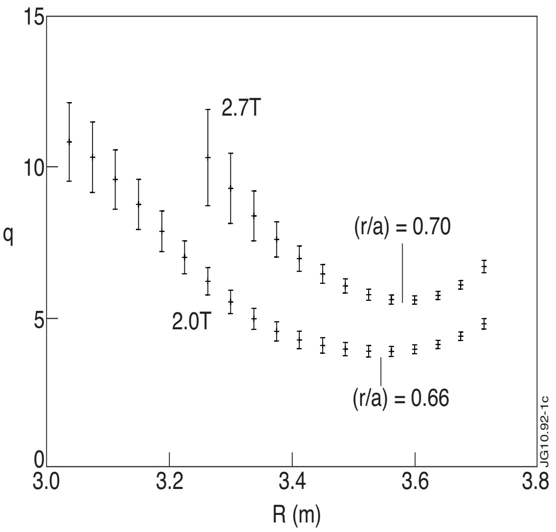

***Figure 1**: q profiles as measured at t_{init}+1.4s by MSE/EFIT for pulses 79650 (2.0T) and 79649 (2.7T).*

Interpretative simulations of the current ramp phase in AT plasmas have been performed with the TRANSP [2] code with neo-classical resistivity (NCLASS) to test the sensitivity of the modelled current profile evolution to the initial q-profile shape assumed. Electron temperature and density profiles were provided by a high resolution Thomson Scattering system and Z_{eff} was from visible Bremsstrahlung measurements. Compared to an assumed initial condition with weak magnetic shear, simulations starting with a deep shear reversed q-profile (from the 2.7T pulse as shown in Fig. 1) and using neo-classical resistivity, can retain a significant difference in q_0 (~15%) as q_{min} reaches 3 (a typical starting point for main heating in JET AT experiments) (figure 2). By the time q_{min} reaches 2 the effect of the initial q-profile is no longer significant, indicating that modelling of plasmas in the hybrid regime, where main heating is typically applied when q_{min} approaches unity, is less sensitive to the initial q-profile assumption. This observation is found to be independent of the resistivity model used.

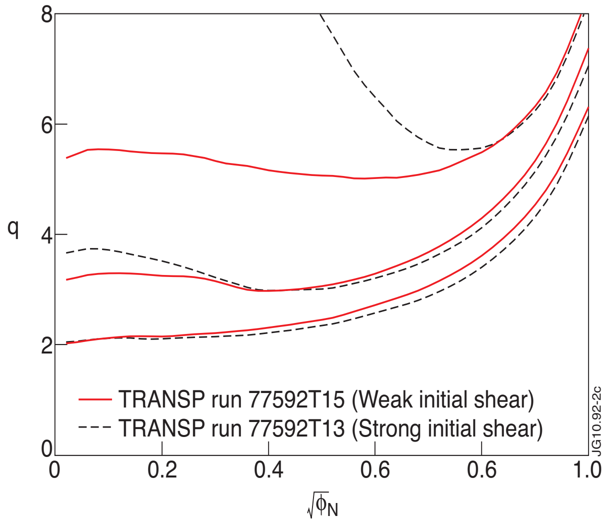

***Figure 2**: Effect of assuming a strong shear-reversed (dashed line- from 79649, t_{init}+1.4s) and weak shear reversed (solid line- from EFIT t_{init}+1.4s) initial q-profile (top) in simulations modelling flux diffusion until q_{min}=3 or q_{min}=2.*

Previous modelling of the current ramp phase of JET AT experiments, assuming a broad initial current density profile and neoclassical resistivity, produced current profiles that were too peaked compared with MSE measurements when q_{min} reached 1.5 [3]. A similar discrepancy is apparent when modelling more recent experiments. Despite the use of a realistic initial q-profile from the measurements described above, the current diffusion into the plasma centre, modelled by TRANSP with neo-classical resisitivity, is too fast when

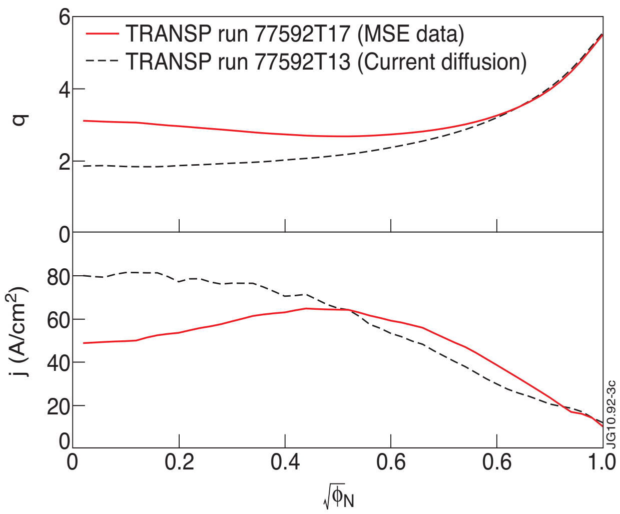

***Figure 3**: Comparison, at start of main heating phase, between MSE data (solid) and simulation (dashed) of q-profiles and current profiles for AT pulse. The simulation uses a realistic initial q-profile (as in Fig.2) followed by current diffusion.*

compared to the first MSE measurement taken at the start of the main heating phase (figure 3).

The effect is already apparent in analysis of the first 1.5 seconds of a plasma pulse with early MSE measurements which shows that the modelled current penetration into the plasma core with NCLASS is again too rapid compared with the measurements, even if, to test the sensitivity of the modelling to measurement uncertainties, Z_{eff} was arbitrarily set to unity (figure 4). Simulations employing different resistivity models (again with Z_{eff} = 1) showed that Spitzer resisitivity (η_{Sp}~ $Z/Te^{3/2}$) gave a closer agreement to the measured current diffusion in this initial current ramp.

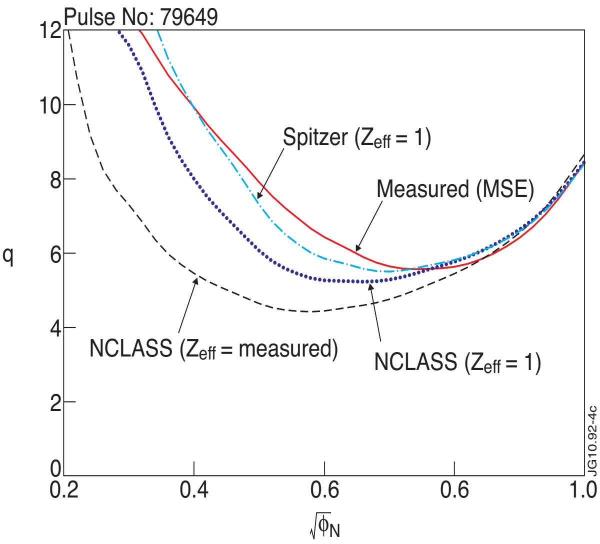

Figure 4: *Comparison of measured and simulated q-profiles at t_{init}+1.4s for pulse 79649 after 0.3s of modelled current diffusion. Z_{eff} is assumed to be flat across the plasma.*

These results contrast with the good agreement of modelling and MSE data for the hybrid plasma q-profile once it has reached stationary conditions. This is tested in experiments where the main heating was extended to 3 resistive times (τ_R ~ 4.5s), there is no appreciable discrepancy between the MSE measured q-profile and an interpretative simulation using neo-classical current diffusion for the entire duration of the simulation (figure 5).

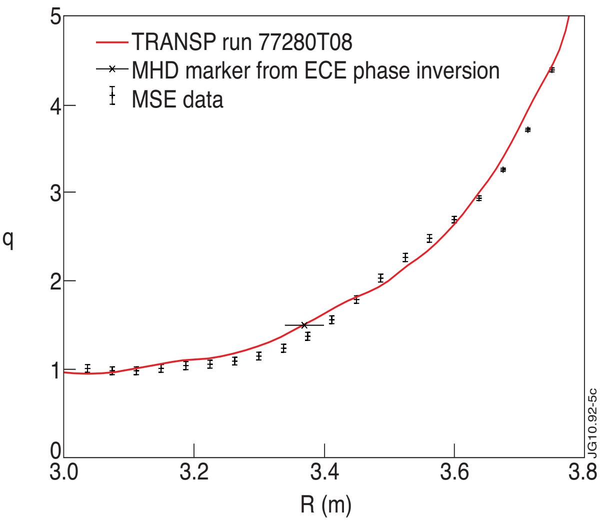

Figure 5: *Comparison of q-profiles (at 16.5s after start of main heating) from MSE data with TRANSP simulation using MSE measured initial q-profile at t=4.55s. The location of the 3/2 mode from ECE inversion is also shown as an additional experimental marker for q=1.5 surface.*

In conclusion, firstly it has been shown that the effect of initial q-profile assumption can affect the modelling of AT scenarios. There can be a significant difference in q_0 when q_{min} approaches 3 between simulations using an as-measured deeply shear-reversed q-profile compared to a weakly shear reversed one (as previously assumed). The initial assumption does not appear to be important by the time q_{min} reaches 2. Additionally, the current profile evolution in the ramp-up phase does not appear to be neo-classical. Thus the heating target q-profile for steady-state regimes (where q_{min} >2 when main heating is applied) cannot necessarily be satisfactorily modelled, whereas where the main heating phase is delayed as for the hybrid regime (where q_{min} ~1 at the start of main heating) satisfactory agreement between simulation and MHD markers has been observed which gives confidence in the q-profile modelled as the plasma approaches stationary conditions. It should be noted that electron colllisionality (ν^*_e) is much higher in the Ohmic current ramp plasma compared to high β_N hybrid/stationary plasmas (Figure 6). Successful modelling at low ν^*_e but not at high ν^*_e suggests the need for further model validation in high ν^*_e plasmas where the effects of trapped particles are critical.

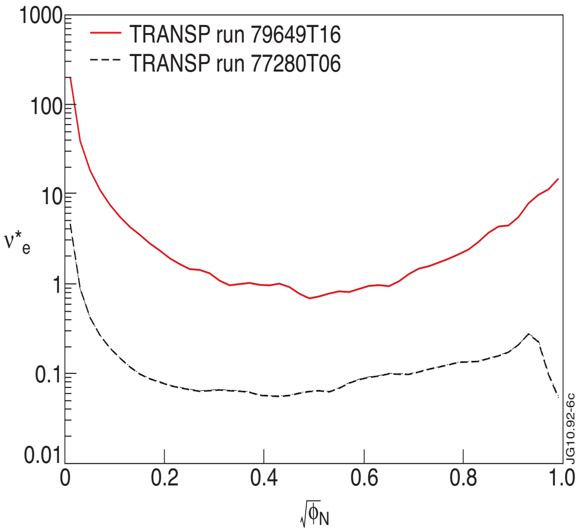

***Figure 6**: Log10 plots of electron collisionality profiles for (solid) current ramp pulse 79649 at t_{init}+1.5s , and (dashed) stationary regime pulse 77280 at t=16.5s after start of main heating.*

Inconsistencies between measurement and modelling in the highly dynamic current ramp phase have been observed on other devices and this issue should be addressed for validation of predictive simulations for present and future machines.

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