Determination of the requirements for the sustainment of hybrid scenarios on JET

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Abstract

In the framework of non-equilibrium phase transitions, the role of the poloidal current density profile has been identified as critical for the transition to stationary advanced regimes in tokamaks [1]. It gives a measure of how close an advanced scenario is from good current alignment and can be used as a tool to calculate the additional requirements needed in order to improve transient advanced regimes. These features are applied to optimize JET hybrid scenarios.

Introduction

In confined plasmas, the different plasma regimes (or scenarios) have specific configurations which are characterized by different current density, pressure profiles and confinement properties. Some examples are the L and H modes, Internal Transport Barrier (ITB) regimes and the Hybrid or advanced inductive regime. In a recent paper [1], theoretical arguments have been put forward, proposing a method to quantitatively discriminate these scenarios in stationary conditions and to give precise recipes for the transition to stationary advanced scenarios. This theory involves the poloidal current density j_θ. As it was shown in [1] by the example of the three main ITER scenarios, j_θ in the plasma core (i.e., except for the pedestal region) is qualitatively and globally different for the inductive H-mode and the noninductive ITB regime. It undergoes a global sign change (not only in the reversed q profile - high pressure region), which can be used to identify the regimes precisely. The Hybrid and advanced regimes with no ITB naturally appear as the transition point between the two, with a globally flat and close to zero j_θ profile (not only in the flat q region). A simple analytical criterion was derived to identify the three regimes and define the possibility of transition between them. In order to extend the scope of the verification of these features, several JET hybrid scenarios are going to be used.

[*] See the Appendix of F. Romanelli et al., Proceedings of the 23rd IAEA FEC 2010, Daejeon, Korea

Role of poloidal current

In recent campaigns, hybrid scenarios in JET have achieved high confinement H_{98y2}=1.3-1.4 with β_N~3 at high and low triangularity [2] for duration of about one resistive time. A plasma current overshoot technique was used to prepare the target q-profile and produce a high magnetic shear region in the outer half of the plasma and a low central shear in the inner half with q_0~1. Despite a high amount of non-inductive current, (~50%), some of them display a clear evolution of the q profile which tends to shrink the low magnetic shear region in the plasma core.

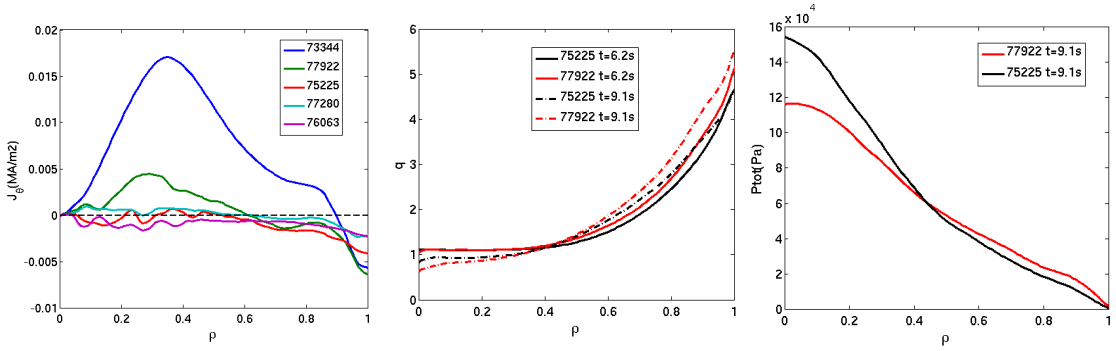

Figure 1. Poloidal current density profiles for different JET shots (a) Time evolution of q profile for shots 77922 and 75225 (b) Pressure profile for shots 77922 and 75225 (c)

In order to check the role of j_θ on these scenarios, in figure 1a, the experimental poloidal current, calculated with the CRONOS code [3], is shown for 5 discharges: the H-mode shot 73344 and the advanced hybrid shots, 77922 (at high density and high pedestal) and 75225, 77280 and 76063 (at low density and low pedestal). As expected, j_θ is bell-shaped and positive (except for the pedestal region) for shot 73344, whereas for the hybrid shots it is flat and close to zero. However, the shot 77922 has a somewhat intermediate structure. This has an impact on the time evolution of the q profile and the pressure profile. In figure 1b, the evolution of q is plotted for shots 77922 and 75225 (both with the same total current, 1.7MA, and NBI input power). Although at t=6.1s the q profile is very similar for $\rho<0.5$, with a vanishing magnetic shear region, after 2.9s, it clearly evolves more for the shot 77922. The pressure profile, shown in figure 1c, is more peaked at ρ =0.35 for the shot 75225 than for shot 77922,. This extra peaking contributes to increase the bootstrap current in that region, something that has been identified as essential to sustain hybrid scenarios [4].

In fact, the pressure profile needed to achieve the condition j_θ=0 can be evaluated with $\nabla P_{crit} = j_\varphi^{crit} B_\theta^{crit}$ being $j_\varphi^{crit} = j_\varphi(j_\theta = 0) = \frac{(j_{ohm} + j_{cd})}{1-\varepsilon^{1/2}}$ the critical toroidal current [1], with ε the inverse aspect ratio. In figure 2a and 2b, the comparison between the experimental pressure and the theoretical one is shown. Since, j_θ~0 for shot 75225, the theoretical pressure

profile obtained is in agreement with the experimental one, however, for shot 77922 it is below the requirement. Using the approximated expression $j_{bs} = \varepsilon^{1/2} RP'$, the pressure profile can be translated into bootstrap current needed or the external current drive sources requirements. As shown in figure 2c, the bootstrap current for the shot 77922, although having a similar shape to that expected from the condition j_θ=0, it is slightly under the requirements. This can be reason why the q profile cannot be properly sustained.

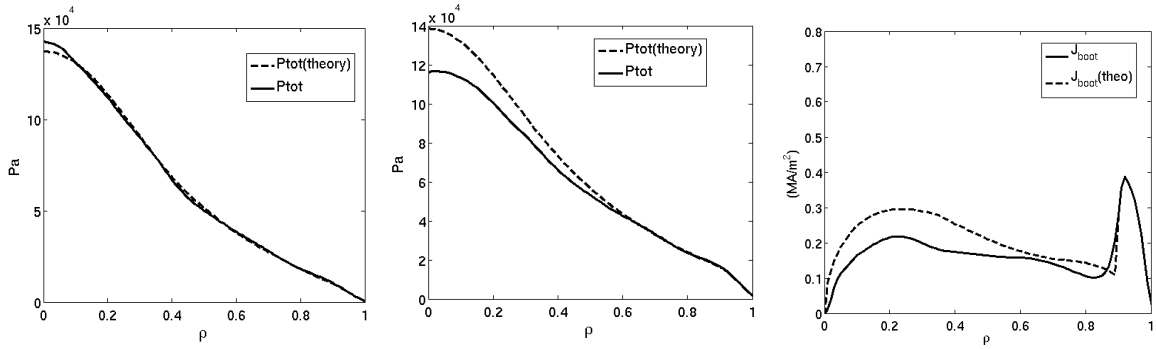

Figure 2. Comparison between the theoretical pressure profile and experimental one for shot 75225 (a) Comparison between the theoretical pressure profile and experimental one for shot 77922 (b) Comparison between the theoretical bootstrap current density profile and the experimental one for shot 77922 (c)

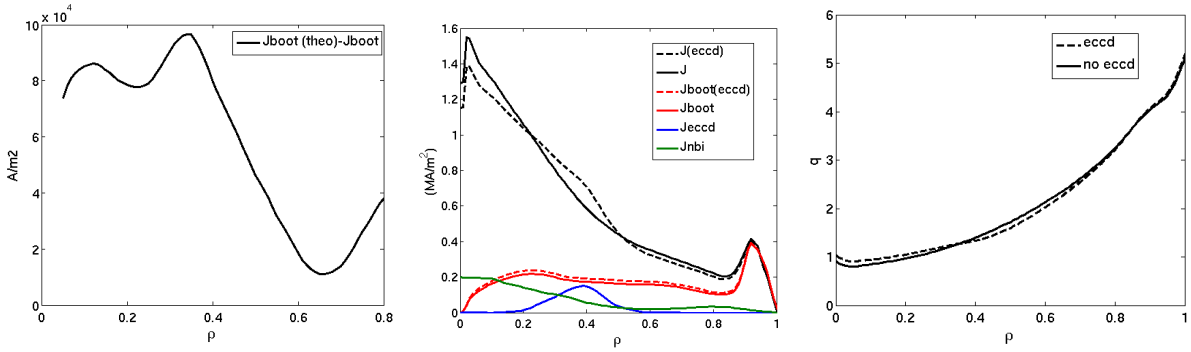

Figure 3. Missing current for shot 77922 (a) Current configuration with and without the additional ECRH/ECCD power (b) q profile with and without the additional ECRH/ECCD power (c)

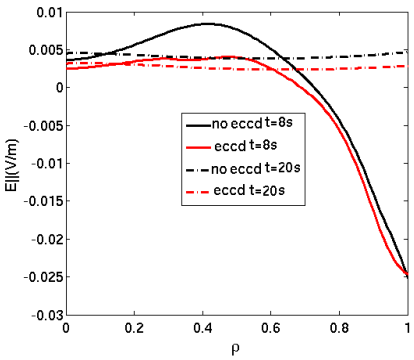

Figure 4. Parallel electric field, E||, at t=8s and t=20s for the simulation with and without ECRH/ECCD

Since the current configuration is known at j_θ=0, the extra current needed can be easely calculated. In figure 3a, the difference between the theoretical boostrap current and the experimental one is shown. The missing current, 150kA, is mainly located at $0<\rho<0.5$ with an off-axis current maximum located at ρ=0.38. A predictive simulation is then performed with the Bohm-gyroBohm transport model [5] and CRONOS with the aim of analyzing wheter the inclusion of this missing current could tailor the q profile by stoping the shrinking of the

flat shear region. As an example, 4 MW of extra ECRH/ECCD located at ρ=0.38 are used to provide such current. The current drive obtained, 90kA, together with the extra bootstrap current, 60kA, obtained from the increased electron temperature, give the total missing current. In figure 3b and 3c, the current configuration at t=20s (almost 3 current diffusion times) with and without the extra power and the q profile obtained are compared. In the case where the extra current has been added, the q profile is flatter in the core and very close to 1. As shown in figure 4, the profiles are very close to stationary conditions since the parallel electric field is almost flat at t=20s.

Application to ITER

In order to extrapolate the JET hybrid scenarios to ITER, the condition j_θ=0 is used as a fixed point. For that purpose a scenario with 20MW of ECRH/ECCD, 20MW of ICRH, 33 of NBI and a fixed confinement factor H_{98y2}=1.3 has been considered. In figure 4a, the poloidal current for the H-mode and hybrid scenarios for JET and ITER are compared, showing that they are quite similar, since, in fact, the current configurations for both, shown in figure 4b, are also comparable. The bootstrap current fraction is 40% with β_N~2.7, as usually obtained in hybrid scenarios. The q profile is also quite similar to the one obtained for JET.

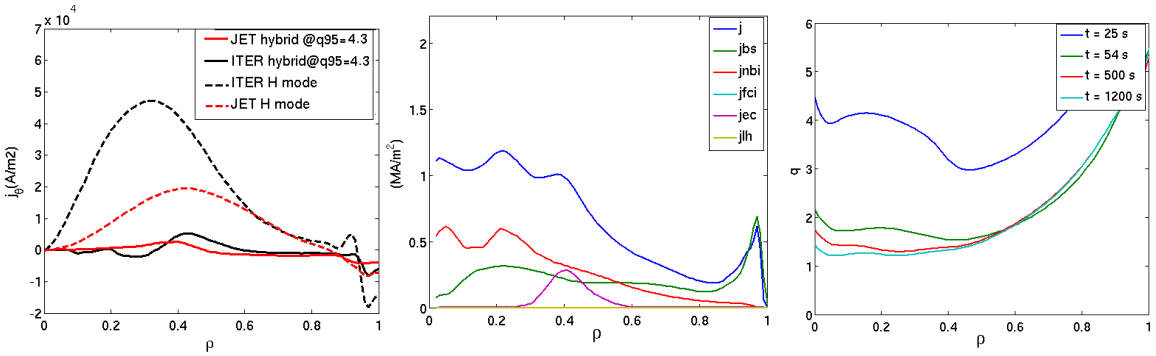

Figure 5. Poloidal current density for JET and ITER H-mode and hybrid scenario (a) Current configuration for the ITER hybrid scenario (b) Evolution of the q profile for the ITER hybrid scenario (c)

Acknowledgments

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