Initial low recycling improving confinement and current drive in advanced tokamak (AT) and hybrid scenarios

R Cesario[1], L Amicucci[1], G. Artaserse[1], I T Chapman[2], M Marinucci[1], F Jenko[3], I Lupelli[2],
M Romanelli[2], S Saarelma[2], D Told[3], and JET EFDA contributors*
JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK
[1]*ENEA UT Fusione Fisica del Confinamento Magnetico, CP65, 00044 Frascati, Italy*
[2]*/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK*
[3]*Max-Planck-Institut für Plasmaphysik, 85748 Garching, Germany*

Abstract. To improve stability and confinement in fusion plasmas via sufficient control of the plasma current profile represents a major objective for the progress of thermonuclear fusion research based on the tokamak concept. The lower hybrid current drive (LHCD) would provide a solution, by removing the problematic extrapolation of LHCD to high plasma densities, as demonstrated on FTU. However, since LHCD is not approved yet in ITER and is difficult to foresee its presence in DEMO, the issue remains on how producing a high bootstrap fraction (f_{bs}>50%) in the unfavorable condition of relatively low q_{95} (< 5).

We focus here on the proper (initial) condition of a low particle recycling from the vessel wall, which should be performed before starting the main heating phase, as useful for enhancing the bootstrap current density at large radii of the plasma column. Experiments in ITER-like wall, relevant to hybrid scenario with $q_{95}\simeq4.5$ and performed with an initial compression and expansion of plasma volume with the aim of changing the q-profile, exhibited a lower initial recycling, a higher electron temperature of periphery, and a higher normalised β (β_N) in H-mode. A similar effect of the initial level of recycling was found in statistics of plasma discharges performed in C-wall, relevant for AT scenario with $q_{95} \simeq 5$.

Modelling of current density profile evolution shows that a larger bootstrap current occurs at large radii in case of lower initial recycling, effect of larger electron temperature produced at large radii. Analysis of microinstability in L-mode phase shows that ETG modes have smaller linear growth rate in case with lower recycling. From stability analysis performed during the high β_N phase, a bigger margin of stability minimum shear occurs near the plasma periphery, thanks to current drive improved by the proper initial edge condition.

Introduction

Experiments of JET aimed at approaching fully non-inductive ITER-relevant conditions, with plasma shaped with high triangularity $\delta \simeq 0.4$, $q_{95} \simeq 5$ (I_P=1.5MA B_T=2.3T) produced new records of normalised β ($\beta_N \simeq 2.8$, $H_{98} \simeq 1.05$) for about ten confinement times, during an ELMy H-mode phase in TB discharges (e.g. discharge 70069) [1,2]. Considering data of these experiments, previous work [3] showed that to operate with a lower recycling before the start of the main heating phase (at $t=t_{NB}$) produced by neutral beam (NB) and ion cyclotron resonant heating ICRH) power, should be a pre-requisite for producing during H-mode a higher β_N phase, characterised by a lower magnetic shear near the pedestal radial layer.

We summarise here this phenomenology. *i*) The high β_N discharge (shot 70069, $\beta_N \simeq 2.8$) was obtained by previous reference discharge (68927) utilising slightly different operating parameters including a markedly lower recycling at $t \lesssim t_{NB}$. This condition was obtained using a larger radial outer gap (of 8 cm in place of 4 cm) with the aim of reducing the plasma-wall interaction before the start of the main heating phase. *ii*) Such a β_N performance did not however appear when using lower hybrid current drive (LHCD) in prelude (e.g., in shot 70068, $\beta_N \simeq 2.6$). In these experiments, LHCD produced an initial higher magnetic shear at the start of the main heating phase, which evidently cancelled the proper initial condition provided by the ohmic prelude. *iii*) Using the same operating parameters of the latter discharge (70068) but lower initial recycling via less gas fuelled in prelude, the previous confinement performance was restored (in discharge 72595, $\beta_N \simeq 2.8$), for the first time in experiments using LHCD in prelude. In the latter experiment, the effect of a lower initial recycling was intentionally explored following the indication obtained for developing the performance pulse (70069), in which the tool of lower initial recycling was used together some other different parameters with respect to previous reference discharge (68927).

Modelling results

Figure 1 compares the radial profile of the bootstrap current density, and Figure 2 the magnetic shear of two AT discharges: the high β_N pulse (70069), using ohmic prelude and having a high β_N phase, and discharge (70068) performed with same operating parameters but LHCD in prelude. The considered time points are kept at the occurrence of higher β_N. A stability analysis has been carried out using the ideal MHD code MISHKA-1 [4] considering the main heating phase. The equilibria for the same plasma discharge of Fig. 1 have been reconstructed from the current density and pressure profiles derived from JETTO [5] simulations. These profiles, together with the fixed boundary shape of the last closed flux surface are supplied to the HELENA code [6], which produce the static equilibrium employed by MISHKA-1. The plasma is found to be stable to infinite-n ballooning modes at the low magnetic shear generated by the strong bootstrap current. However, the plasma discharge (70069) with highe j_{BS}, see Fig. 1, has a bigger margin of stability minimum shear at the plasma periphery ($\Delta s_{min} \approx$ 4.0, $\beta_{Nmax} \approx 2.8$ for discharge 70069) than the plasma with lower β_N ($\Delta s_{min} \approx 2.3$, $\beta_{Nmax} \approx 2.6$ for discharge 70068). Δs_{min} is the minimum distance in magnetic shear between the experimental plasma and the stability boundary.

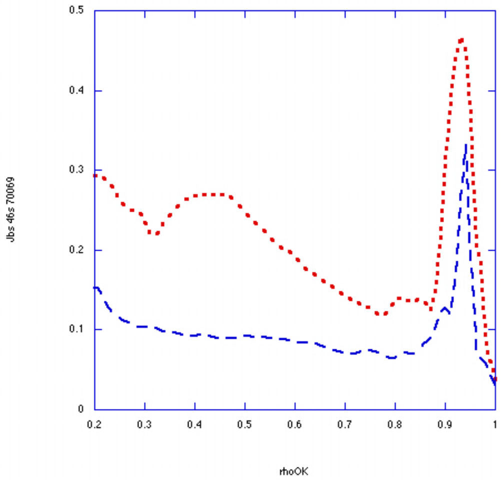

Fig. 1. Bootstrap current density radial profile at the time point at around the occurring maximum β_N: at t=6.0 s in discharge 70069 (red-dotted curve) at t=8.0 s in discharge 70068 (blue-dashed curve).

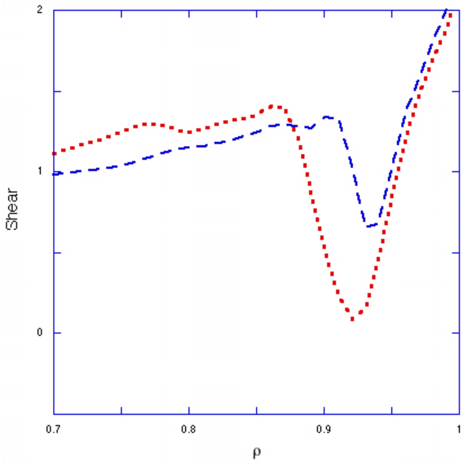

Fig. 2. Radial profile of the magnetic shear of discharge 70069 at t=6.0 s (red-dotted curve), and discharge 70068 at t=8.0 s (blue-dashed curve).

Figure 3 shows the results of microinstability modelling carried out using the GENE code [7] for discharge (72595) that exhibits a high β_N phase thank to initial recycling lower than in reference shot (70068). For the parameters of the latter discharge, which has higher density and lower temperature, ETG modes are predicted to be unstable during the L-mode phase, while they are much weaker (but still slightly unstable) for the compared discharge (72595).

Comments and conclusions

The relevant phenomenology links together parameters of the plasma edge in L-mode (recycling and temperature) and periphery (temperature, bootstrap current density, shear), to H-mode confinement performance. High temperature at the edge favours the occurrence of higher $T_{e\text{-periphery}}$ that, in turn, promotes the occurrence of high $j_{BS\text{-periphery}}$ (by the $T\nabla n$ term) and low $s_{\mathrm{periphery}}$ in building H-mode profiles consistent with current drive data of Fig. 1. The relatively high $T_{\mathrm{e\text{-}periphery}}$ observed in these regimes might be the consequence of microinstability stabilisation that improves confinement via low local shear, resulting in a more stable initial condition of plasma in L mode, as supported by the GENE code results.

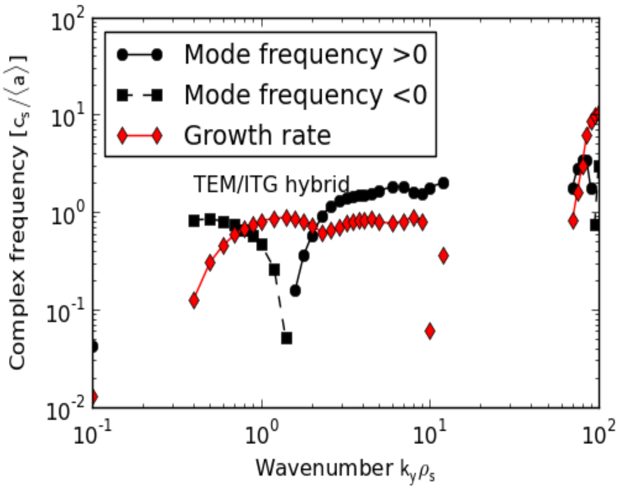

Fig. 3a Microturbulence modeling for L-mode phase before injection of neutral beam power (t=3.2s) made by the GENE code. Discharge 72595. ETG is absent.

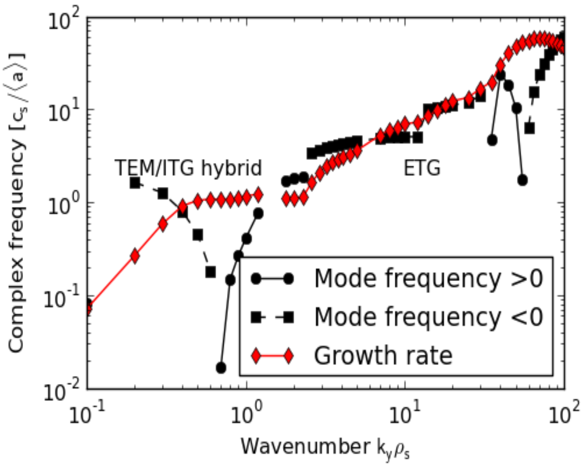

Fig. 3b. Simulations as in Fig 3a but considering plasma parameters of discharge 70068. In this case ETG takes over at higher wavenumber

A sort of *virtuous* feedback, favoured by initial conditions of higher temperature of the edge, seems thus to act and tend to sustain the high β_N phase. The full assessment of the described mechanism, possible by further work of transport and current drive modelling, should lead producing a new tool for fulfilling the critical current drive requirements for fusion plasmas.

ACKNOWLEDGEMENTS

This work was supported by EURATOM and carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission

[*] *See the Appendix of F. Romanelli et al., Fusion Energy Conference 2008 (Proc. 22nd Int. FEC Geneva, 2008) IAEA, (2008)*

References

1. F. Rimini et al., in Proc. of the 22nd IAEA Fus, Energy Conf, Geneva, Switzerland, 2008 EX/1-2)
2. C.D. Challis et al., in Proc. 34th EPS Conf. On Plasma Phys., Warsaw 2007
3. R. Cesario, et al., Plasma Phys. Control. Fusion 55 (2013) 045005 (14pp)
4. B. Mikhailovskii et al, Plasma Phys Rep, 23, 844 (1997)
5. G. Cenacchi, A. Taroni, in Proc. 8th Computat. Plasma Physics, Eibsee 1986, EPS 1986), Vol. 10D, 57
6. G. Huysmans et al, Proc CP90 Conf on Computational Physics, p371 1990)
7. F. Jenko et al., Phys. Rev. Lett. 80, 4883 (1998)]