# COMPATIBILITY OF PRONOUNCED DETACHMENT WITH IMPROVED CONFINEMENT ON HL-2A TOKAMAK

[1]T. WU, [1]M. XU, [1]Z. WANG, [1]L. NIE, [1]Z. H. WANG, [1]J. M. GAO, [1]Y. H. CHEH, [1]Y. R. ZHU, [1]Y. ZHANG, [1]L. LIU, [1]D. LI, [1]K. ZHANG, [1]R. KE, [1]X. X. HE, [1]Z. C. YANG, [1]X. YU, [1]N. WU, [1]Z. H. HUANG, [1]K. Y. YI, [1]L. W. YAN, [1]Y. G. LI, [1]T. LONG, [1]L. Z. CAI, [2]Y. YU

[1]Southwestern Institute of Physics, Chengdu 610041, People's Republic of China
[2]Sino-French Institute of Nuclear Engineering and Technology, Sun Yat-sen University, Zhuhai 519082, China

Email: wuting@swip.ac.cn

Heat load control on the divertor target is a critical issue for International Thermonuclear Experimental Reactor (ITER) and future fusion reactors. The detachment scenario is a promising way to achieve steady state H-mode plasma in ITER [1,2]. However, divertor detachment sometimes leads to degraded core confinement [3-4]. Especially in the pronounced and full detached states [4], excessive impurity accumulation in the main plasma causes confinement degradation [3-4]. Hence, various feedback methods of controlling impurities are employed to avoid excessive impurity injection, so as to improve the compatibility of detachment with core confinement after detachment [5].

Traditionally, the core and edge regions have been studied as isolated regions with different physics, even in L-mode plasmas. In this paper the edge region refers to the region very close to the last closed flux surface (LCFS) and the scrape-off layer (SOL). The core and edge regions have different models in theories and simulations. However, a moment's thought leads to the observation that the edge region is situated immediately adjacent to the core region. In fact, higher ion temperature in the core region is preferred in order to achieve higher fusion power. Meanwhile, a cooling edge, especially a cooling SOL, provides a beneficial path for controlling the heat loads on the plasma facing components and the divertor target when pursuing high fusion power. Hence, the core and edge regions are required to be decoupled to make high plasma performance and effective divertor power exhaust compatible. In this paper, then, we explore the core-edge integration solution which can provide higher ion temperature in the core and lower temperature near the LCFS and the strike point in pronounced detached plasma.

In this study, we have examined the compatibility of pronounced detachment with improved confinement. A combined experimental and simulated approach on HL-2A tokamak. Pronounced detachment is achieved through impurity seeding from divertor on HL-2A tokamak. After pronounced detachment, the maximum decrease in $I_{\rm sat}$ and $T_{\rm e}$ in the outer target are about 84% and 86% respectively; and the maximum $T_{\rm e}$ is less than 5 eV. The total stored energy $W_{\rm e}$ increases by a factor of 15%, and energy confinement time $\tau_{\rm E}$ increases by 24.4%. After pronounced detachment, the total radiation power in the main chamber increases by 24%; NII line emission becomes higher at plasma edge and causes edge cooling; radiation increases significantly near the X-point, which is similar to an X-point radiator.

Edge turbulence and turbulent transport ($k_\theta \rho_{\rm s} \in [0, 1]$) decrease after pronounced detachment. Edge turbulence propagating in the ion diamagnetic drift direction decreases significantly and turbulence propagating in the electron diamagnetic drift direction dominates at plasma edge, as shown in figure 1. The scale and the amplitude of edge turbulence decrease, which could mainly attribute to reduced free energy source due to edge cooling rather than edge poloidal velocity shear (figure 2). The significant reduction of ion turbulent energy flux makes major contributions to the reduced edge total turbulent transport near the LCFS after pronounced detachment. The dominant ion turbulent energy flux and total turbulent energy flux decrease at $\rho \in [0.1, 0.4]$, and ion temperature increase at $\rho \in [0, 0.8]$ after pronounced detachment. The power entering the SOL/divertor decreases after pronounced detachment shown in figure 3(a). The reduced edge outward transport increases the plasma reservoir. The reduced edge outward transport and increased core electron density and ion temperature make major contributions to the increase of the total stored energy and energy confinement time, as summarized in figure 3(b). Hence, the plasma confinement increases after pronounced detachment.

Overall, the pronounced detachment is well compatible with the improved confinement on HL-2A L-mode plasma. The above results indicate that pronounced detachment provides a cooling edge to reduce the outward transport, and this plays a significant role in improving confinement after pronounced detachment. The $T_{\rm i}$ decreases at the edge but increases in the core, making the core and edge decoupled.

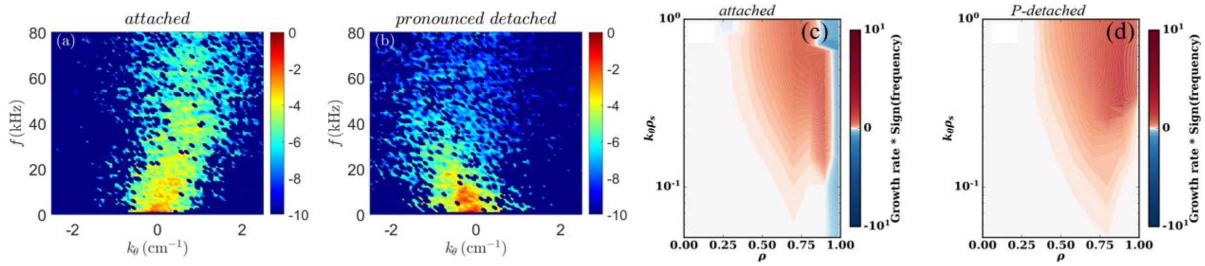


*Figure 2. The poloidal wave number spectrum measured by Langmuir probe arrays (mid-plane) near the LCFS (a) in the attached state and (b) in the pronounced detached state. The largest growth rates of turbulence in the scale range of* $k_\theta \rho_s \in [0, 1]$ *(c) in the attached state and (d) in the pronounced detached state. Blue represents turbulence propagating in the ion diamagnetic drift direction and red for turbulence propagating in the electron diamagnetic drift direction.*

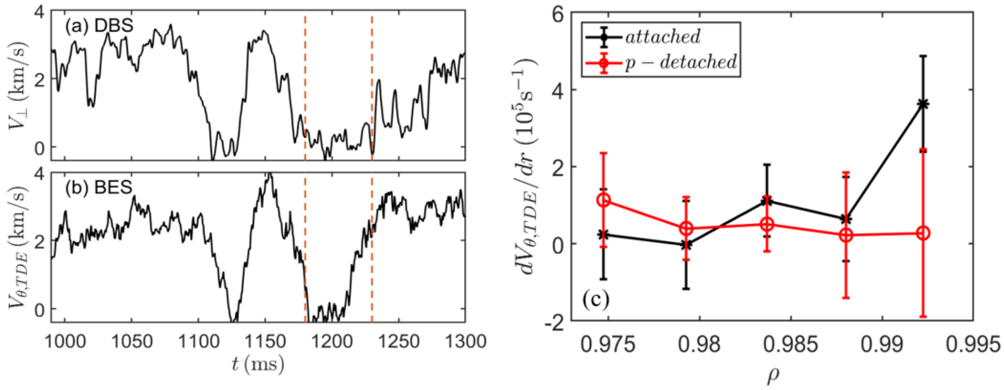


*Figure 1 Time evolution of poloidal velocity measured by (a) DBS and (a) BES near LCFS in shot #38008, and (c) the poloidal velocity shear measured by BES at the edge in the attached* ($t = 1000\ ms$) *and pronounced detached states* ($t = 1200\ ms$)*. Here* $\rho$ *is the normalized minor radius, and "p-detached" represents the pronounced detached state.*

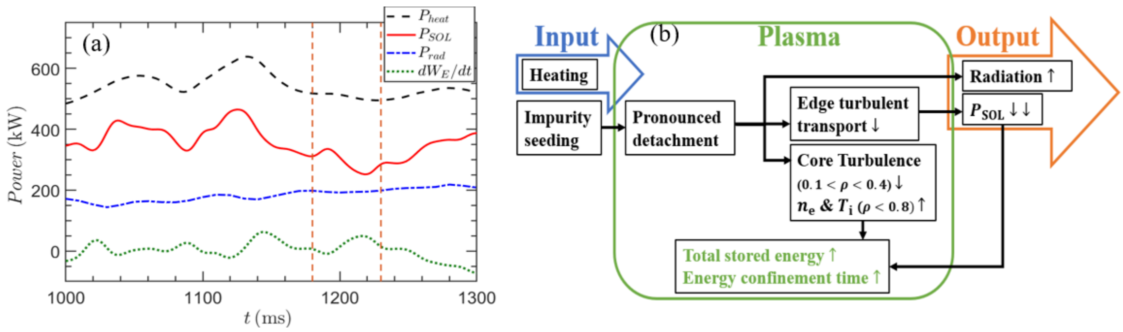


*Figure 3 (a) Time evolution of heating power* $P_{heat}$*, the power entering SOL/divertor* $P_{SOL}$*, total radiation power in the main chamber* $P_{rad}$ *and time-variation of the total stored energy* $dW_E/dt$*. (b) A schematic diagram for understanding the compatibility of pronounced detachment with the improved confinement.*

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