Preliminary results of ELMy H-mode experiments on the HL-2A tokamak


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Abstract

Typical ELMy H-mode discharges have been achieved on the HL-2A tokamak with combined auxiliary heating of NBI and ECRH. The minimum power required is about 1.1 MW at a density of $1.6 \times 10^{19} \text{ m}^{-3}$ and increases with a decrease in density, almost independent of the launching order of the ECRH and NBI heating. The energy loss by each edge localized mode (ELM) burst is estimated to be lower than 3% of the total stored energy. At a frequency of typically 400 Hz, the energy confinement time is only marginally reduced by the ELMs. The supersonic molecular beam injection fuelling is found to be beneficial for triggering an L–H transition due to less induced recycling and higher fuelling efficiency. The dwell time of the L–H transition is 20–200 ms, and tends to decrease as the power increases. The delay time of the H–L transition is 10–30 ms for most discharges and is comparable to the energy confinement time. The ELMs with a period of 1–3 ms are sustained for more than ten times the energy confinement time with enhanced confinement factor $H_{95} > 1.5$, which tends to decrease with the total heating power. The confinement time in the H-mode discharges increases with plasma current approximately linearly.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

The first H-mode discharge was observed on the ASDEX tokamak with a neutral beam injection (NBI) power of ~3 MW in 1982 [1]. The energy confinement time in the discharges was shown to increase to twice of that in L-mode discharges and close to that in Ohmic discharges. The H-mode was reproduced on PDX with a NBI power of 6 MW in 1984 [2], on DIII-D with a NBI power of 6 MW in 1986 [3] and on JET with a NBI power of 10 MW in 1987 [4]. Later, the H-mode was also realized with a pure ion cyclotron resonance heating (ICRH) power of 1.1 MW on ASDEX [5], and with a sole ECRH power of 0.7 MW on DIII-D [6]. The first H-mode in a stellarator was achieved on W7-AS with an electron cyclotron resonance heating (ECRH) power of 0.4 MW in 1993 [7]. A spontaneous L–H transition was also observed on the Large Helical Device (LHD) with a NBI power of 6 MW [8]. Ohmic H-modes are routinely obtained on TCV [9, 10]. Significant progress on H-mode operation and physics has been made and major results are reviewed [11–15].

The H-mode plasma often induces a so-called edge localized mode (ELM), a kind of MHD instability, manifesting as bursts in the $H_\alpha$ ($D_\alpha$) emission in the divertor region and plasma periphery, which is one of the typical characteristics of H-mode operation [16, 17]. The peeling–ballooning instability model is usually applied to describe the driven mechanism for the ELM oscillations [18]. Recently, H-mode with ELMs has been proposed as a possible operation scenario for the ITER because it is compatible with all the ITER exhaust requirements, i.e. $f_{\text{rad}} \sim 75\%$, $f_{\text{GW}} \sim 0.85$, $q_{95} \sim 3$, $Z_{\text{eff}} < 2$, outer divertor detachment, and most notably, $\Delta W_{\text{ELM}}/W_{\text{ped}} < 0.01$ [19, 20].

An L–H transition requires a minimum power threshold $P_{\text{th}}$, which depends on the magnetic field configuration, bulk ion species, wall condition, fuelling location, direction of the magnetic gradient drift of the ions, etc. Once these conditions are optimized, the power threshold can be estimated as follows [17] for deuterium discharges:

$$P_{\text{th}} = 0.042n_0^{0.73}B_t^{0.74}S^{0.98}. \quad (1)$$

A power threshold $P_{\text{th}} = 52$ MW has been estimated for ITER, using the parameters of density $n_e = 0.5 \times 10^{20} \text{ m}^{-3}$, magnetic field $B_t = 5.3$ T and plasma surface area $S = 680 \text{ m}^2$. According to equation (1), the power threshold in HL-2A is...