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Comparison of plasma parameters between QH and ELMing phases of the same discharges

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Abstract

H-mode confinement is observed for many energy confinement times without edge localized modes (ELMs) in QH (quiescent high-confinement)-mode discharges in DIII-D [1]. To find critical differences between ELMing and QH modes we compared electron temperature (T_e), density (n_e), and ion temperature (T_i), in the pedestal and scrape-off layer (SOL) for a group of discharges. We also compared the electron pressures P_{ped}, and maximum pressure gradients $P_{e,ped,max\ grad}$ because of their importance in confinement and stability.

Experimental results show that the core line averaged density, median T_e (pedestal), SOL T_e, and T_e pedestal width, and SOL T_i are nearly the same in QH mode as that during ELMs. The n_e (average pedestal), n_e pedestal width, $P_{ped,}$ and $P_{e,ped,max\ grad}$ are similar to corresponding values in QH mode and at various times between ELMs. However, the pedestal T_i is 1.6 times higher in QH mode than during ELMing.

JNM keywords: P0500 Plasma Materials Interaction, P0600 Plasma Properties

PSI-16 keywords: DIII-D, divertor, Edge pedestal, SOL Plasma boundary

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I. Introduction

This paper presents a statistical comparison of several important plasma parameters in QH-mode and ELMing H-mode. Quiescent high confinement (QH) mode is exhibited in DIII-D tokamak plasmas with H-mode confinement, long periods with no edge localized modes (ELMs), and constant plasma parameters [1-4]. QH-mode has been seen in ASDEX-U [5], JET [6], and JT60-U [7] and is of interest for avoiding ELM-induced damage to the divertors of future large tokamaks. Observed requirements for QH-mode include neutral beams injected opposite to the plasma current, relatively low plasma density, and a large gap between the outer wall and the plasma separatrix (g_{out}). The edge n_e and T_e profiles in QH-mode are similar to those of H-mode [8].

We examine time slices from a group of discharges exhibiting both QH and ELMing H-mode behavior, and compare the plasma parameters between the two modes for different times during the ELM cycle. The discharges have been selected with nearly the same toroidal field (2.0±0.05 T), plasma current (1.3±0.05 MA), and upper single-null magnetic configuration. The ion temperature data have been further selected for 9.5 cm< g_{out} <10.5 cm.

II. Procedure

Nearly all the QH discharges exhibit ELMing H-mode at some time during the pulse, often shortly after the neutral beam counter-injection begins. ELMing was often followed by a transition to quiescent behavior at the same confinement and nearly the same density. The plasma parameters analyzed include: electron pedestal temperature ($T_{e,ped}$) and density ($n_{e,ped}$), T_e and n_e pedestal width, maximum electron pressure gradient ($P_{e,ped,max\ grad}$), electron pedestal pressure ($P_{e,ped}$), scrape-off layer (SOL) T_e and n_e, pedestal ion temperature ($T_{i,ped}$), and SOL T_i. Far SOL values from the modified hyperbolic tangent fit were used for the electron SOL temperature and density. The ion temperatures were obtained from charge-

exchange recombination spectra of carbon. Electron temperature and density profiles were obtained using modified hyberbolic tangent fits to Thomson scattering data [9]. The SOL value used was from the far SOL part of this fit. Electron pressure was calculated from the product of the electron density and temperature. The maximum electron pressure gradient was from the analytic derivative of the modified hyperbolic tangent.

The QH-mode data were treated as a single group, and statistics of the plasma parameters were obtained. The ELM electron data were separated into groups by ELM phase and the statistics for each phase were determined. The ELM phase is defined as the time since the last ELM divided by the time between the last ELM and next ELM peak in D_α , as measured at the outer midplane. For these discharges, the time resolution of the ion temperature data is not sufficient to separate it by ELM phase, so T_i is considered in one group averaged over ELM phase.

In the figures, square symbols represent the median value of a quantity during ELMing at a particular ELM phase, circles are the average value, and a band depicts the median QH value. The height of the band represents the error bar. Some of the figures use a suppressed zero to better illustrate small variations. The size of all error bars is $\sigma/\sqrt{n}$ where σ is the standard deviation of the sampled quantity and n is the number of samples.

III. Results

A. Electron temperature

Immediately after an ELM, the pedestal T_e drops 10%–15% and then recovers its pre-ELM value before the next ELM. The QH-mode pedestal median electron temperature is slightly (2%) higher than in any part of the ELMing phase [Fig. 1(a)].

The electron temperature in the SOL shows a 25% drop after an ELM pulse, nearly twice the change in the pedestal. The QH value is nearly the same as the highest inter-ELM value

[Fig. 1(b)]. The median T_e pedestal width is essentially unchanged during the ELM cycle (but the mean T_e pedestal width rises), and is the same in the QH and ELMing phases [Fig. 1(c)].

B. Electron density

The median electron pedestal density ($n_{e,ped}$) increases abruptly, then more gradually, after an ELM, until the next ELM, when it drops quickly [Fig. 2(a)]. In this data set the highest value of $n_{e,ped}$ is 35% more than the lowest $n_{e,ped}$. The QH value of $n_{e,ped}$ is nearly the same as the lowest value during ELMing, which occurs shortly after the ELM (ELM phase ~5%).

The SOL density drops at the time of an ELM pulse, then rises sharply to a plateau, which is held until the next ELM. The QH SOL density corresponds to the plateau level during ELMing [Fig. 2(b)].

The width of the electron density pedestal is largest immediately after an ELM, then decreases a factor of two, reaching a plateau value until the next ELM. The width during QH-mode corresponds to the plateau level during ELMing [Fig. 2(c)].

C. Ion temperature

The median pedestal T_i is much higher in QH-mode than during ELMing (Fig. 3), by a factor of 1.6, even though similar densities, input power levels, and energy confinement occur in the two phases.

The SOL T_i is similar in QH-mode to that during ELMing (Fig. 4).

D. Electron pressure in the pedestal

The median electron pressure $P_{e,ped}$ at the top of the pedestal [Fig. 5(a)] drops by ~40% shortly after an ELM, and recovers before the next ELM. The QH value of $P_{e,ped}$ is intermediate between these extremes. This supports the idea that in QH-mode the ELM is

replaced by another mode, usually the continuous edge harmonic oscillation (EHO) which appears to regulate the pedestal particle confinement and pedestal pressure.

The maximum electron pressure gradient in the pedestal $P_{e,ped,max\ grad}$ shows a dramatic change over an ELM cycle. The ELMing $P_{e,ped,max\ grad}$ is 30% less steep than the QH -mode gradient immediately after an ELM pulse, steepens to the QH value at 15% ELM phase, then at later ELM phase reaches 40% steeper than the QH gradient. Clearly the continuous nature of the EHO maintains some average $P_{e,ped,max\ grad}$ in contrast to the ELMs, probably due to the EHO ejecting particles from the plasma.

IV. Discussion

Each of the averaged parameters examined for the ELMing H-modes attains a similar value to QH-mode values at some particular ELM phase, although the precise timing differs for each parameter. The exception is T_i in the pedestal, which is consistently higher during QH-mode.

The $T_{e,ped}$, SOL T_e, and T_e pedestal width, do not show a large difference from a constant ELM value in this data, within limits of the error bars. The value of $n_{e,ped}$ for QH-mode matches ELMing H-mode at an ELM phase of 5% and clearly does not match later ELM phases. The SOL n_e for QH-mode is close to ELMing n_e for ELM phase $\geqq$20%. The width of the n_e pedestal for QH-mode agrees with the ELMing value for ELM phases $\geqq$45%. Both the $P_{e,ped}$ and $P_{e,ped,max\ grad}$ for QH-mode agree with ELMing H-mode for an ELM phase of 15%. The $T_{i,ped}$ values for QH-mode are 1.6 times the respective values in ELMing H-mode.

The tempting conclusion is that the higher ion temperatures are responsible for producing QH-mode, although uncertainties in the data may not justify this, nor is this a complete examination of the plasma behavior. However, our results do place a constraint on any model

seeking to explain QH-mode. Database work can be a useful guide, but does not take the place of detailed experimental comparisons. Within this set of discharges are a variety of plasma shapes, heating power, momentum input, edge current (not measured in this data set), and other variables. All have effects on the pedestal stability limit and transport. Nevertheless, the data in this paper indicate that QH mode parameters remain within the range of time variation for ELMs except for T_i. Possibly the difference in ion temperatures is caused by fast ions in QH mode, which may play a role in stabilizing the ELMs.

Acknowledgment

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References

[1] K.H. Burrell, *et al.,* Phys. Plasmas **8** (2001) 2153.

[2] C.M. Greenfield, *et al.,* Phys. Rev. Lett. **86** (2001) 4544.

[3] W.P. West, *et al.,* Phys. Plasmas **9** (2002) 1970.

[4] W.P. West, K.H. Burrell, and J.S. deGrassie "Quiescent H-mode, an ELM-free High-Confinement Mode on DIII-D with Potential for Stationary State Operation," Proc. 30th Euro. Conf. on Control. Fusion and Plasma Physics, St. Petersburg, Russian Federation, 2003 (European Physical Society, Geneva) CD-ROM.

[5] W. Suttrop, , *et al.,* Plasma Phys. Control. Fusion **45** (2003) 1399.

[6] W. Suttrop private communication (2003).

[7] Y. Sakamoto, private communication (2003).

[8] W.P. West, *et al.,* Plasma Phys. Control. Fusion **46** (2004) A179.

[9] R.J. Groebner and T.H. Osborne, Phys. Plasmas **5** (1998) 1800.

Captions

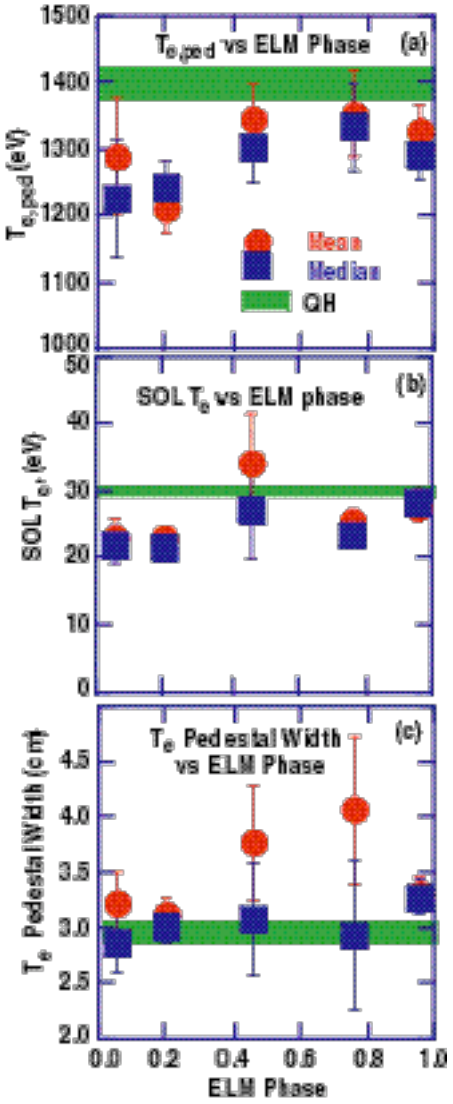
Fig. 1. (a) $T_{e,ped}$ vs ELM phase, (b) SOL T_e vs ELM phase, (c) T_e pedestal width vs ELM phase. In this and succeeding figures, square symbols represent median values during ELMing, circles denote average values during ELMing, and the band represents the value during QH mode.

Fig. 2. (a) $n_{e,ped}$ vs ELM phase, (b) SOL n_e vs ELM phase, c) n_e width vs ELM phase.

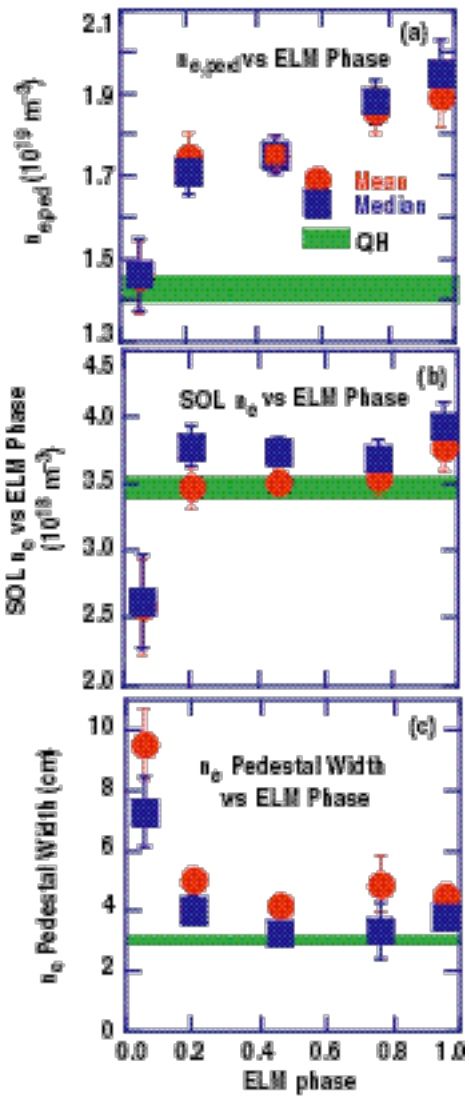
Fig. 3. (a) Histogram of $T_{i,ped}$ during QH-mode, (b) for ELMing.

Fig. 4. (a) Histogram of SOL T_i during QH-mode, (b) for ELMing.

Fig. 5. (a) $P_{e,ped}$ vs ELM phase (b) Maximum gradient of $P_{e,ped}$ vs ELM phase.



C.J. Lasnier Figure 1



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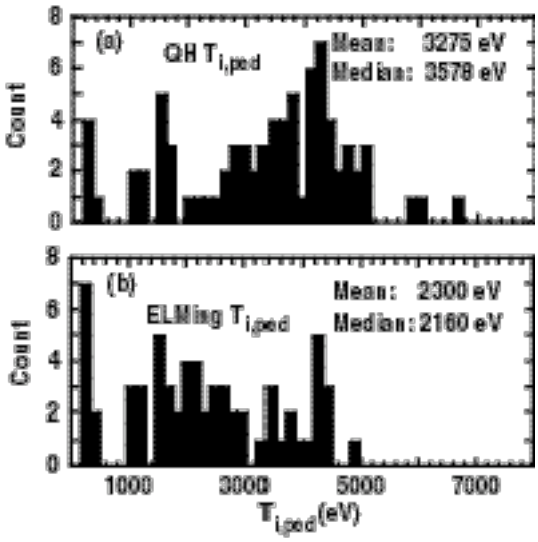
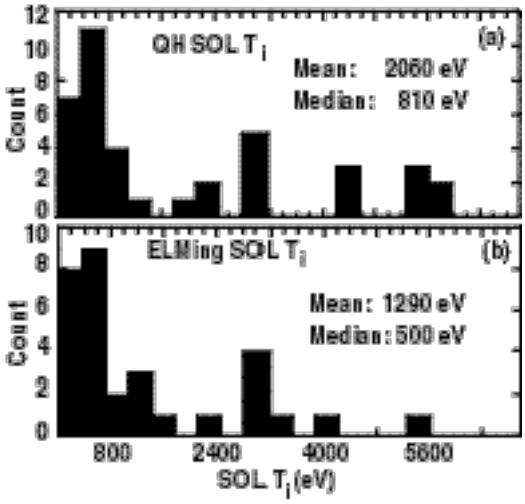
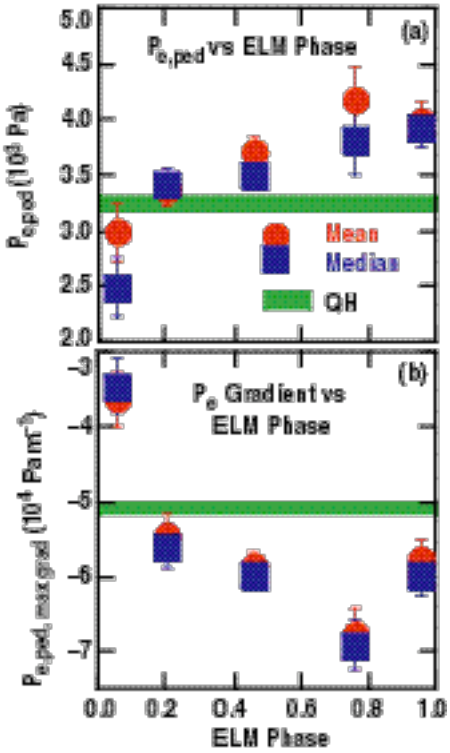


C.J. Lasnier Figure 3



C.J. Lasnier Figure 4



C.J. Lasnier Figure 5

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