CONFINEMENT PROPERTY IN THE JT-60SA FIRST OPERATIONAL PHASE

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Characteristics of global energy confinement of L-mode diverted plasmas in the JT-60SA first plasma operation phase has been investigated. In H_2-gas-injected plasmas with a plasma current I_p of 1 MA, the energy confinement time τ_E clearly depends on total heating power. At a constant total heating power, τ_E increases with an increase in a line-averaged electron density $\bar{n}_e$, indicating that these plasmas are in the linear ohmic confinement regime (LOC). The global energy confinement time is estimated around 100 - 200 ms with the power balance and transient analysis method. The global energy confinement time is compared with the ITER89-P scaling law, resulting in τ_E being on and a little below the scaling. The global energy confinement time dependence on $\bar{n}_e$ matches the neo-Alcator scaling law in the lower-density plasma ($\bar{n}_e = 2 - 5 \times 10^{18}\ \mathrm{m}^{-3}$), and reaches the ITER89-P scaling law in the higher-density plasma ($\bar{n}_e = 6 - 7 \times 10^{18}\ \mathrm{m}^{-3}$) in the similar total input power regimes. The operational regime of JT-60SA in the first plasma operation phase with 1 MA is considered in the LOC regime and achieves the saturated ohmic confinement (SOC) regime in the higher-density regime.

1. INTRODUCTION

Investigation of confinement property in a newly developed large tokamak device is essential and important for its extrapolation to ITER and a future DEMO. Experiments of JT-60SA, which is currently the largest superconducting tokamak device, with a toroidal magnetic field B_T of 2.25 T, a major radius R of ~ 3 m, and a minor radius a of ~ 1.2 m, have been started and already successfully performed its first plasma operation and achieved I_p of 1.2 MA [1, 2]. The energy confinement of the plasmas with plasma current I_p = 1 MA has been investigated with limited diagnostics in the first plasma operation phase. The global energy confinement time, τ_E, has been compared with the L-mode scaling law to evaluate its consistency with energy confinement characteristics of other devices. The global energy confinement time follows the neo-Alcator scaling in the LOC regime, remaining below the ITER89-P scaling [3-5]. At higher densities, the confinement characteristics transition toward the SOC regime, where τ_E is on the ITER89-P scaling. The results are also compared with the neo-Alcator scaling due to the lower density operation in the JT-60SA first operational phase.

2. DEPENDENCE OF GLOBAL ENERGY CONFINEMENT TIME

Table.1 Parameter ranges

Parameter	Value
I_p	1 MA
B_T	2.0 T
P_{OH}	0.48 – 0.82 MW
P_{ECH}^{inj}	0 or 0.49 MW
GP	0 – 3.57 Pa m^3 /s
$\bar{n}_e$	2.5 – 6.5 $\times 10^{18}$ m^{-3}
$T_e(\rho = 0.1)$	0.8 – 1.8 keV
R	3.07 – 3.09 m
a	1.26 – 1.28 m
W_{st}	66 – 225 kJ
κ	1.49 – 1.53
δ	0.38 – 0.41
q_{95}	13.1 – 13.6

The ranges of the engineering and plasma parameters are summarized in Table. 1. Here, P_{OH}, P_{ECH}^{inj}, GP, $T_e(\rho = 0.1)$, W_{st}, κ, δ, q_{95} are the ohmic heating power, the injection power of ECH, a flux rate of gas puffing, an electron temperature at a normalized minor radius ρ of 0.1, the stored energy, elongation, triangularity, and an edge safety factor, respectively. Here, q_{95} is defined by the empirical model shown in [6]. A beam trajectory of the EC wave is calculated by PARADE code [7], and the absorbed power of ECH P_{ECH}^{abs} is evaluated under cold plasma approximation and a flat density profile ($n_e \propto 0.9(1-\rho^{16}) + 0.1$), which is 80 - 90% of P_{ECH}^{inj}. The ohmic heating power is evaluated from a one-turn loop voltage and I_p.

The global energy confinement time is evaluated from the energy balance equation ($\tau_E = \mathrm{W_{st}}(\mathrm{P_{ECH}^{abs}} + \mathrm{P_{OH}} - \mathrm{dW_{st}/dt})^{-1}$) and validated by a decay time of W_{st} after ECH stops. The energy confinement time is from 100 ms to 200 ms. Figures 1(a) and (b) show dependencies of τ_E on the total heating power $\mathrm{P_{total}} = \mathrm{P_{OH}} + \mathrm{P_{ECH}^{abs}}$, and $\bar{n}_e$, respectively. The relationship between τ_E and $\mathrm{P_{total}}$ at the constant $\bar{n}_e$ indicates a

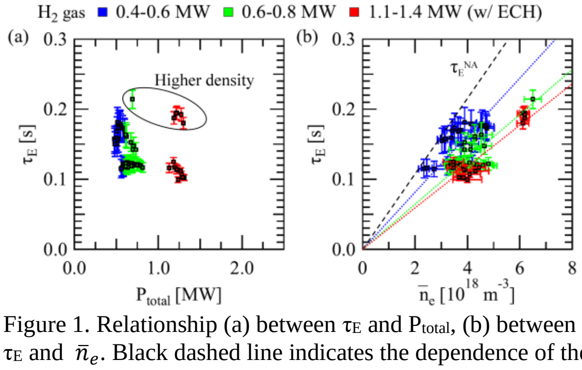

Figure 1. Relationship (a) between τ_E and P_{total}, (b) between τ_E and $\bar{n}_e$. Black dashed line indicates the dependence of the neo-Alcator scaling law on $\bar{n}_e$. Blue, green and red lines are the best fit for the data in each heating power range.

decrease of τ_E with increasing P_{total} and the variations in τ_E for the similar P_{total}. The energy confinement time tends to increase with $\bar{n}_e$ as shown in the fitted lines in Fig. 1(b). The global energy confinement time is on / below the neo-Alcator scaling [5] and the gradient of the fitted curves of τ_E decreases with an increase of the heating power. The threshold density is estimated between $3 – 4 \times 10^{18}$ m^{-3} according to the reference [5], where the most points are found. However, τ_E depends on $\bar{n}_e$ linearly even in the higher density regime than the threshold density in the plasma with P_{OH}=0.6 – 0.8 MW and the ECH plasma. In KSTAR, the core electron heating with the core ECH increases the threshold density [8]. The linear dependence even in the higher density regime is consistent with the KSTAR's result.

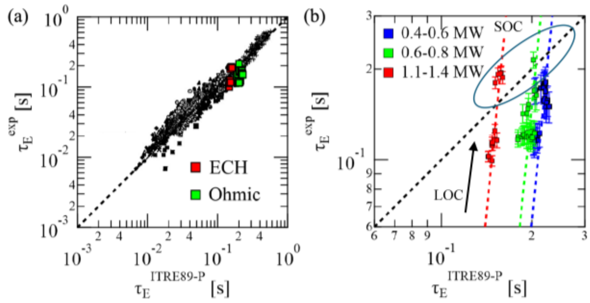

Figure 2. (a) Comparison of τ_E with the ITER89-P scaling. (b) Comparison of τ_E with the neo-Alcator scaling on the enlarged view of (a). Black arrow and blue circle are eye guides indicating the range of LOC and SOC, respectively.

3. COMPARISON WITH SCALING LAW

The global energy confinement time is compared with the ITER89-P scaling law ($\tau_E^{ITER89-P} = 0.038 I_p^{0.85} B_T^{0.2} P_{total}^{-0.5} \bar{n}_e^{0.1} M^{0.5} R^{1.2} a^{0.3} \kappa^{0.5}$). Because most of the data in the database refer to the SOC regime as mentioned in the reference [4], this formula suggests a weak dependence on $\bar{n}_e$. In Fig. 2(a), τ_E shown in Fig. 1 is compared with the ITER89-P scaling law, which is overplotted on the scaling result in the reference [4]. The experimental result of τ_E matches or is about a factor of two shorter than the ITER89-P scaling law.

The operational regime of this dataset is discussed in terms of the LOC / SOC regimes, The discussion focuses on P_{total} and $\bar{n}_e$ as other parameters related to the ITER89-P scaling law are almost constant as shown in Table 1. For the separation of an impact of P_{total} on τ_E, the dependence of τ_E on $\bar{n}_e$ in the similar P_{total} is investigated. In the LOC regime, τ_E matches the neo-Alcator scaling law in terms of the dependence on $\bar{n}_e$[5]. In Fig. 2 (b) which is an enlarged view of Fig. 2(a), the linear dependence of τ_E on $\bar{n}_e$ as a function of $\tau_E^{ITER89-P}$ for the data in the ranges of P_{total} =0.4 - 0.6, 0.6 - 0.8 and 1.1 - 1.4 MW are overplotted. Because the experimental data is almost on the curve for each power regime, τ_E of the JT-60SA plasma in the first plasma operation phase with I_p = 1 MA has a proportional dependence on $\bar{n}_e$ and achieves the ITER89-P scaling in the higher-density cases with $\bar{n}_e \sim 6 – 7 \times 10^{18}$ m^{-3}. In the previous study, τ_E depends on $\bar{n}_e$ as τ_E^{NA} in the LOC regime and matches $\tau_E^{ITER89-P}$ in the SOC regime [5]. In the case of the JT-60SA L-mode diverted plasmas with I_p = 1 MA in the first plasma operation phase, the lower-density plasmas are considered to be in the LOC regime, while the higher-density plasmas are likely in the SOC regime.

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