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Scaling of Edge Pedestal Parameters Using the International Pedestal Database

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1. Introduction

One of the features of the H-mode regime is the existence of a steep gradient in the temperature and density profiles near the plasma boundary. The region of steep gradients is often referred to as the H-mode transport barrier or more loosely the "edge pedestal". The understanding of edge pedestal characteristics has been recognized as an important issue of investigation, as it strongly influences the prediction of the plasma performance for future magnetic fusion devices.

The edge pedestal parameters scaling has been studied separately in each machine so far. Several attempts have been made on parameter dependence of the pedestal width. However, studies show that the parameter dependence of the pedestal width is rather different, e.g., some machines observe an ion poloidal Larmor radius dependence, while in others such a dependence is not observed. A complication is that different experiments can be in different H-mode regimes and measure different pedestal parameters. This scaling study focuses on the type I ELM regime, and the pedestal pressure using the multi-machine pedestal database is compared with existing models.

2. Multi-machine pedestal database

To research the universal edge pedestal characteristics, an international multi-machine pedestal database has been built. The first version of the database, which was installed during 1997, archives the pedestal data from major divertor Tokamaks, ASDEX-Upgrade (AUG), Alcator C-MOD (C-MOD), DIII-D, JET and JT-60U. Additional JT-60U and AUG data have recently been supplied to the database. Pedestal parameters in the database are summarized in Table 1. Missing data in the data base is estimated using the following assumptions: (1) $T_e^{PED}=T_i^{PED}$ except JT-60U. (2) The pedestal pressure and its gradient are defined $p^{PED}=kn_e(T_e+0.6T_i)$, $\nabla p^{PED}= p^{PED}/\Delta$, respectively (i.e. $Z_{eff}=3.0$ with main impurity being carbon). (3) Poloidal magnetic field $B_p=\mu_0 I_p/(2\pi a((1+\kappa^2)/2)^{0.5})$ which is used to calculate ρ_{pi} (poloidal Larmor radius) pedestal is an averaged value.

To compare pedestal parameters among multi-machine data, the pedestal width Δ and the pedestal height (T_e^{PED}, T_i^{PED}, n_e^{PED}) should be derived using the same definition. The most reliable data may be obtained from a hyperbolic tangent (*tanh*) fit to the pedestal region with appropriate linear terms[1]. If the data are not enough to perform *tanh* fits, the pedestal width and height are then estimated using a linear fit to the data. Note that, while the edge measurements are made at various poloidal locations in the different machines, all the data have been mapped to the low B_t side midplane.

In this study, data during the Type I ELMy phase are extracted from the database and analysed. This is the largest subset of data presently available and allows comparisons to several theories and single machine fits (see Sections 3 and 4). Since C-MOD has not observed regular Type I ELMs, we are not concerned with C-MOD data.

Table 1. Pedestal parameters in the database.
Open circle symbols show data existing. Square symbols show assumption.

	AUG	C-MOD	DIII-D	JET	JT-60U
T_e^{PED}	O	O	O	O	O
T_i^{PED}	□	□	□	□	O
n_e^{PED}	O	$0.66\bar{n}_e$	O	O	O
width	T_e,n_e	–	T_e,n_e	–	T_i
p	□	–	□	□	□
p'	□	–	□	–	□
Pedestal location	tanh fit	ψ=95%	tanh fit	Linear fit	tanh fit
Edge stability	1st	?	2nd	1st	1st

3. Parameter dependence of pedestal width

The pedestal width scaling for ELMy H-modes has been studied separately on several machines: $\Delta_{Ti} \propto \rho_{pi} q_{95}^{-0.3}$ on JT-60U [2]; $(\Delta_{pe}/R) \propto (\rho_{pi}/R)^{0.6}$ or $(\Delta_{pe}/R) \propto (\beta_p^{PED})^{0.4}$ on DIII-D [3]. In this study, we focus on the temperature pedestal width Δ_T and assume $\Delta_{Te} = \Delta_{Ti}$. The dependencies of Δ_T on ρ_{pi} and β_p^{PED} are shown in Fig. 1, respectively. The JT-60U and DIII-D data separately have positive correlations with ρ_{pi} and β_p^{PED} but are in both cases well separated from each other. It is thus difficult to prefer one dependence over the other. The spread of the AUG data is too small to establish trends but the measured widths, when

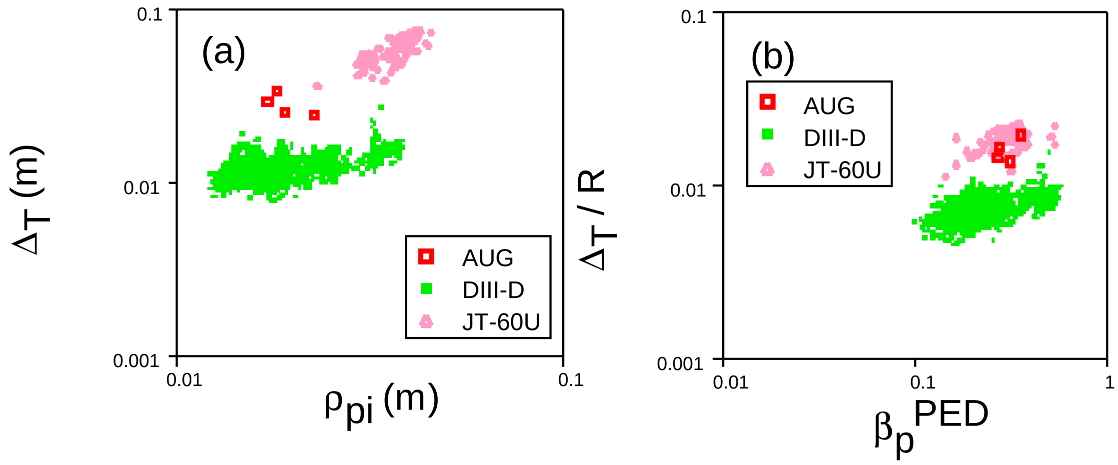

Figure 1. The dependencies of Δ_T on ρ_{pi}(a) and β_p^{PED}(b)

normalized to machine major radius, fall in the same range as the JT-60U data.

4. Comparison between existing model and that in the database

As the beginning, we compare between the pedestal pressure by an existing scaling[4] and p^{PED}. From the offset non-linear scaling, the thermal stored energy W_{th} in an ELMy H-mode plasma is expressed as follows;

$$W_{th} = 0.082\kappa R a I_P B_t (B_t R^{1.25})^{-0.1} + 0.043 R^{1.3} a (I_P n_{19} P)^{-0.15} \qquad (1)$$

The first term indicates the offset part determined by the MHD stability of the ELM. If we assume that the first term corresponds to the pedestal stored energy, p^{PED} can be expressed $p^{PED} \propto I_P B_t/a$ (i.e. $W \propto p V_P$). The relation between p^{PED} and $I_P B_t/a$ is shown in Fig. 2. It seems that AUG, DIII-D, JET and JT-60U data are well fitted on $I_P B_t/a$.

From Sugihara's model[5], p^{PED} is expressed as follows.

$$p^{PED} = \nabla p_c^{PED} \times S \times \Delta \propto B_t^2/(Rq^2) \times S \times \rho_{tor} S^2 \propto I_P/q(mT^{PED})^{0.5} S^3 \qquad (2)$$

where ∇p_c^{PED}, S and ρ_{tor} are critical pressure gradient determined by the ideal ballooning mode, the magnetic shear and toroidal Larmor radius, respectively. Note that the second stability regime is out of scope in this model. If magnetic shear effect is omitted, equation (2) can be reduced to $p^{PED} \propto I_P/q_{95}(T_e^{PED})^{0.5}$. The relation between p^{PED} and $I_P/q_{95}(T_e^{PED})^{0.5}$ is shown in Fig. 3. AUG and some DIII-D data split from JET and JT-60U data, though the pedestal pressure for every machine also shows positive correlation against $I_P/q_{95}(T_e^{PED})^{0.5}$. However, JET and JT-60U data has clear dependence on $I_P/q_{95}(T_e^{PED})^{0.5}$ within the database. From statistical view point, we have attempted to derive a scaling for p^{PED} using a free fit and compare free fit and two scalings from existing models as we mention above. The free fit is shown in Figre 4. The root mean square (RMS) value of $I_P B_t/a$ scaling (RMS=1615) is close to free fit (RMS=1309) compared with $I_P/q_{95}(T_e^{PED})^{0.5}$ scaling (RMS=1943). Using engineering parameters (*Ip, Bt*, *R*, *a*) the resulting scaling has a large scatter. Possible reasons are other, hidden, parameters or the quality of data in the current database.

5. Relation between pedestal width and critical pressure gradient

The pedestal pressure gradient ∇p_c^{PED} can be expressed as $\nabla p_c^{\mathrm{PED}} = p_c^{\mathrm{PED}}/\Delta_T$ if $\Delta_T = \Delta_p$ is assumed. We examine the relation between ∇p_c^{PED} and $B_t^2/(2\mu_0 R q_{95}^2)$ as shown in Fig. 6. The parameter $B_t^2/(2\mu_0 R q_{95}^2)$ corresponds to the critical pressure gradient determined by the high n ideal ballooning mode. A parameter of $\nabla p_c^{PED}/\{B_t^2/(2\mu_0 R q_{95}^2)\}$ indicates the α-parameter for ballooning stability. The ∇p_c^{PED} data show a positive correlation against $B_t^2/(2\mu_0 R q_{95}^2)$ for every machine. However the DIII-D data and the other data are split as shown in Fig. 5. The edge plasma in AUG, JET and JT-60U is thought to be in the first stability regime [6]. On the other hand, the edge of most DIII-D H-mode plasmas is thought to be in the second stability regime and limited by low n instabilities [3]. This difference may explain the separation between DIII-D and other data in both the pedestal pressure gradient (Fig. 5) and the pedestal width (Fig. 1).

Let us consider the relation between pedestal width and pressure gradient. If the pedestal width is normalized by poloidal Larmor radius[2], relation between $\Delta_{Ti}/\rho_{pi} q_{95}^{-0.3}$ and α-parameter is shown in Fig. 6. Since the pedestal width is thought to be related to the width of electric shear region or to the region of second stability access, and the alpha-parameter to the low or high n stability limit, it is interesting that the two parameters are so well correlated, even across apparently very different regimes. From the relation, it seems that the pedestal width will be narrow if the pressure gradient is large and vice versa.

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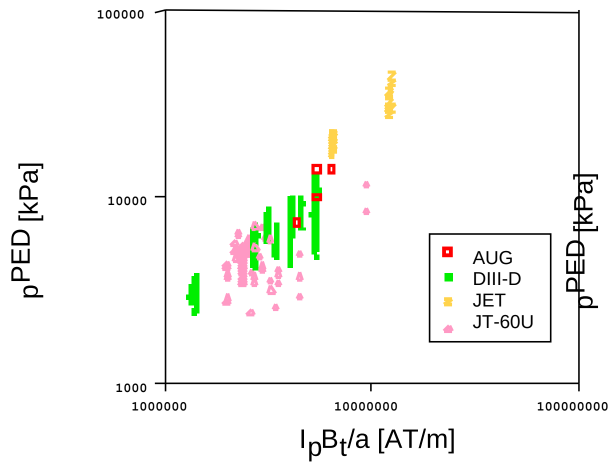

Figure 2. Relation between p^{PED} and I_pB_t/a

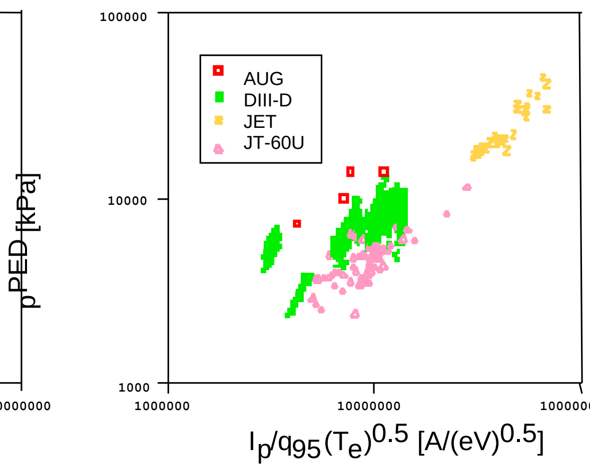

Figure 3. Relation between p^{PED} and $I_p/q_{95}(T_e)^{0.5}$

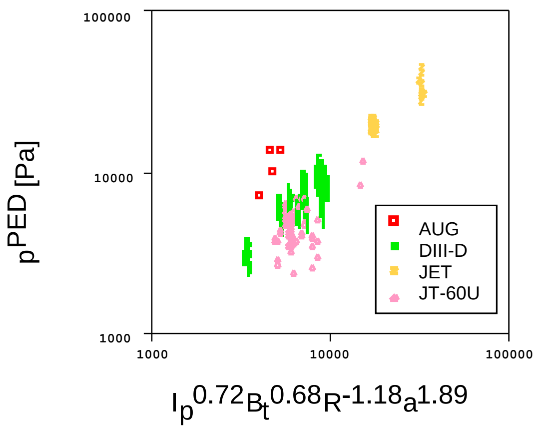

Figure 4. Free fit for p^{PED}

Using engineering parameters (I_p,B_t,R,a) the resulting scaling has a large scatter.

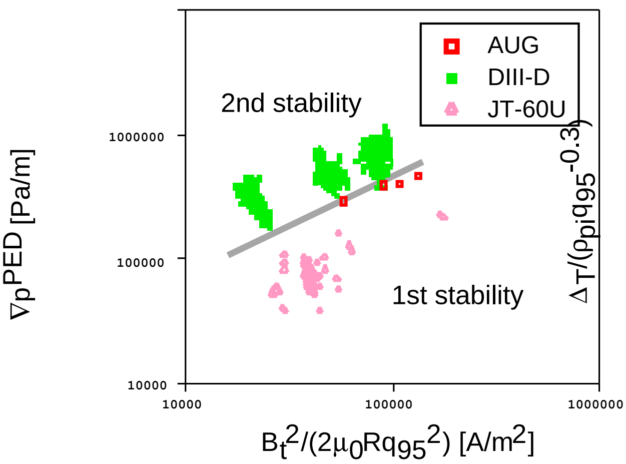

Figure 5. Relation between ∇p^{PED} and $B_t^2/(2\mu_0 R q_{95}^2)$

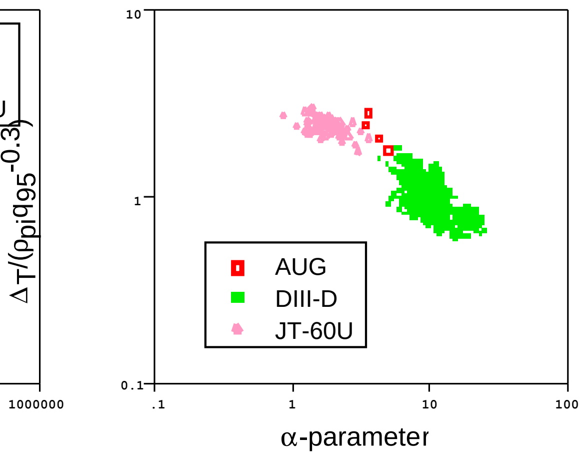

Figure 6. Relation between $\Delta_T/(\rho_{pi}q_{95}^{-0.3})$ and α-parameter