CORRELATIONS OF ELM FREQUENCY WITH PEDESTAL PLASMA PROPERTIES

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Abstract

JET data for the correlations between pedestal plasma temperature and density with the frequency of different type ELMs are analyzed in the framework of a classical Focker-Planck approach. In first approximation we derive a functional dependence in steady state of ELMs assuming equality between the outward flux of plasma from the core and the loss of plasma from the pedestal into the SOL. In this assumption one expects equality between ELM frequency and Coulomb collisionality in the pedestal plasma. Our analysis of JET and TCV data shows that the derived formula for density dependence on temperature is obeyed in wide range of ELM size (including ELM III) but with varying coefficient that corresponds to the configurations of the engineering parameters. The values of this constant differ from that in the Focker-Planck solution for diffusion transport indicating the impact of non-diffusion transport.

1 Introduction

The edge localized mode (ELM) with small loss of power is a preferable scenario for the International Tokamak Experimental Reactor (ITER). The expected loads of plasma on the targets motivate the study of this phenomenon and necessitate the search for approaches to control its impact on the target material.

The results from a recent study of the correlations of ELM frequency with pedestal plasma characteristics [1] based on JET [2] and ASDEX [3] data suggest that this analysis can be extended to small ELM discharges with high frequency. Here we use data for ELM discharges in TCV for the edge of plasma and near divertor targets [4], [5]. They facilitate the derivation of conclusions for the mechanism of plasma transport in the scrape off layer (SOL).

2 Data analysis

A general formula for the relation between pedestal plasma temperature and density in case of large ELMs:

$$n = -a\,c\frac{T^{3/2}}{b\,c\,T^{3/2}-1}, \qquad (1)$$

was derived in [1] using the solution

$$\tau_{ped} = c\,\frac{T^{1.5}}{n}\;s \qquad (2)$$

of the Focker-Plank equation for the conditions of the plasma in tokamak experiments, assuming Coulomb collisions and diffusion transport of plasma $c = 1.2\,10^{18}$). A linear dependence of ELM frequency (f_{elm}) on pedestal plasma density

$$f_{elm} = a + b\,n\,, \qquad (3)$$

was assumed which is in accord with the observations of large ELMs [1]. An assumption for thermal equilibrium between plasma components was also made implying equality between pedestal plasma relaxation time τ_{ped} and the relaxation time of ELMs ($\tau_{elm} = 1/f_{elm}$).

In accordance with the first thermodynamic principle it was assumed that in the stationary state of ELMs the loss of pedestal power ΔW in a particular discharge is compensated by the heating power of expanding plasma after the collapse during the relaxation time ($\tau_{ped} \simeq 20-30$ms [2]). In quasi-equilibrium state of ELM's oscillations the total power is constant in the large time scale of stationary plasma confinement:

$$W_{ped} = \frac{3}{2}\,n\,(T_e + T_i)\,V_{ped} = \text{const} \qquad (4)$$

In such scale the volume V_{ped} is also constant and the temperature of pedestal ions T_i is equal to that of electrons T_e. The small inward power flux from the SOL has been neglected in the previous approach. We call the post collapse plasma heating time the plasma relaxation time, neglecting the time of plasma collapse (about $200\mu s$ [11]).

Two extreme cases of ELMs were expected: 'conductive' and 'convective'. The former are characterized with relatively low density (remaining almost constant), and high pedestal temperature (leading to intensive X-radiation and large loss of energy). For the 'convective' ELM's the functional dependence

$$f_{elm} \sim n \tag{5}$$

fails at relatively high density and large particle losses are expected while the temperature of pedestal plasma remains relatively low and almost unaffected.

For particular conditions of ELM discharges in JET and ASDEX experiments the parameters a and b in eq.3 have been defined empirically [1]. The correlations between pedestal temperature and density obey the eq.1 but for various values of the parameter C(see Table 1). Reduced C in the generalized Focker-Plank equation (2) indicates to faster recover of ELMs caused by additional non-difusion transport of hot plasma from the core to the edge (might have convective or another nature).

Now we use eq.2 to analyze TCV data for the dependence of the relaxation time of ELMs on pedestal plasma characteristics. For the TCV shot 20703,in the beginning of ELM turbulence with frequency 200 Hz (presented in Fig.1 of paper [4]),the temperature at the pedestal is about $0.9\,keV$ and the density of pedestal plasma is about $7\,10^{19}$. Inserting these values in eq.2 we obtain for $C = 0.4\,10^{18}$, that is about 3 times less than the value for pure diffusion transport). It indicates to some additional transport of plasma (might be convection) accelerating ELM's recover. The same value for C ($0.4\,10^{18}$) is obtained for a TCV shot with ELM frequency 250 Hz [5], pedestal temperature $200\,eV$ and density $10^{19}\,m^{-3}$. These results agree with those obtained earlier [1] from the analysis of JET and ASDEX data despite of the large difference in the size of reactors and the size of ELMs. One could assume that we deal with the same non-diffusion transport accelerating ELM recover but in different extent depending on the engineering factors.

We have perform a similar analysis (using eq.2) of TCV data near divertor targets. For ELM discharges with frequency $197 \pm 28\,Hz$, (shot 20493 presented in Fig 10 of paper [4]) the temperature and the density near the outer strike point are estimated over the period $0.5 - 0.8\,sec$. They and shown in Fig. 18 of paper [4]. The values of plasma temperature and density in the moment of the start of ELM's recover are respectively $20\,eV$, $5\,10^{18}\,m^{-3}$. They are inserted in eq.2 and provide to larger value for C (about $9\,10^{18}$ indicating slow transport of plasma through the SOL. Similar results could be obtained using the maximum values of plasma temperature and density during ELM oscillations.

Despite of the small statistics (only published data are used)the present analysis helps in finding direction for investigation of plasma transport dynamics.

In order to show how plasma transport is hampered by the magnetic field in the SOL we have used our PIC simulations of tokamak plasma in the SOL .

3 Simulation results

Here we present some results from our PIC simulations of ELM-produced particles and their transport in the scrape off layer. They are obtained with 'Sofia' version of the BIT1 code [6] in which the 'maximum probability scheme' and all Monte Carlo procedures from the original XPDP1 code [7] have been replaced by exact calculations of colliding particle number and procedures with normalized probability. The new scheme allows to reproduce experimental rates of simulated processes and to account properly for the collisions with relatively small probability.

Except the Coulomb collisions between charged particles , their elastic scattering from D atoms, excitation and ionization of D atoms by electrons, charge exchange between D atoms and ions, in the 'Sofia' code it was implemented multi-step ionization procedures used in the recent BIT1 simulations [8]. In addition we insert new procedures for radiative and two-body recombination processes between charged plasma particles using predictions of the Statisical model [9] for recombination processes in thin plasma updated with compiled [10] new data.

A linear (1D) ('diod'-like) geometry of the SOL was assumed with cross section 10^{-4} . The length of simulated volume was decreased 882 times comparing with the real connection length $48\,m$ from the inner to the outer target of TCV reactor along the field line within 2-3 mm from the separatrix.

It was assumed injection of outward flow of 'computer particles' (each one represents $8\,10^{9}$ pairs of electron and Deuterium ion). Particle 'source' is symmetrically located in the middle of the 'diod' with a length $8.667\,10^{-3}\,m$ in the separatix crossing $'X'$ point.

During ELM turbulence it was assumed constant injection of particles from the 'source' with constant intensity $4\,10^{25}\,part/m^{3}/sec$. Their thermal energy was $113\,eV$ for plasma components assuming dynamic equilibrium between them in the pedestal region.

As an inward flow we have simulated recycling electrons using the corresponding procedure in the BIT1 code [6].

In Fig. 1 we show the time variation of the number of 'computer particles' and the difference between the two component numbers ($N_i - N_e$). There are shown the corresponding variations of the potential ($P\,V$) in the LHS and RHS targets. (A fragment of this picture is presented on Fig.2 in a larges scale).

On Fig.1 one can see periodic 'drops' of particle number in the SOL due to absorbed particles arriving in the targets as dense 'blobs'. Periodical minimum of particle number in the SOL (like the periodic collapses of ELM discharges) are in synchron with the pikes of the potential in the both divertor caused by the considerable loads of plasma particles. More than 30% of particles in the SOL are lost, being absorbed in the target material.

The average time interval for the consequent collapces is about $10\,\mu s$. Multiplying with the scale factor 882 we obtain for the TCV geometry $0.9\,ms$ time for the transport of the blobs in the SOL of TCV discharges. It is comparable with the recover time $5\,milisecs$, of typical TCV discharges with ELM frequency about $200\,Hz$.

4 Discussion and Conclusions

From the comparison in Fig. 1 of the time variation of the number of plasma particles in the SOL with that for the difference between the both components one can suppose a 'blobby' transport of plasma in the SOL during ELM turbulence. 'Blobs' could be caused by the low energy electrons whirling in the strong magnetic field ($2\,T$) and captured in the local field of concentrated Deuterium ions. The group velocity of propagated blobs is about $5.3\,10^4\,m/s$ which is ≈ 2 times less than the average velocity $9\,10^4\,m/s$ of D ions in their propagation towards divertor plates. However the group velocity of the blobs is about 10 times larger than the speed of ELM propagation in the real TCV experiments.

We can expect a better agreement making more adequate assumptions for the magnetic field which is twice less in the TCV experiments. Also in conditions of a thin plasma in the SOL one should take into account the energy loss of electrons for cyclotron emission, inverse compton radiation, electromagnetic cascading. The dynamics of the neutral component should be taken into account.

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Table 1 Experimental conditions (current I, magnetic field B, plasma shape δ, additional heating P_{inp}) for 8 shots with JET and TCV and the corresponding parameters in the approximation formulae: a, b, (eq. 3), c (eq. 2)

Row	JET	$I[MA]$	$B[T]$	δ	$P_{inp}[MW]$	a	$b.10^{-18}$	$c.10^{18}$
1	DOC-1	1.2	1.2	0.27	07	-57.20	2.96	3.0
2	DOC-1	2.0	2.4	0.27	12	-164.28	5.22	1.2
3	DOC-U	2.0	2.4	0.32	12	-401.91	10.19	1.2
4	DOC-U	2.0	2.4	0.32	17	-318.35	10.10	0.5
5	DOC-U	2.5	2.7	0.32	14	-37.96	1.21	2.2
6	HT3	2.0	3.2	0.42	18	-428.50	9.83	0.8
Row	TCV	$I[MA]$	$B[T]$	δ	$P_{inp}[MW]$	a	$b.10^{-18}$	$c.10^{18}$
7	20703	0.4	1.43	0.55	0.5			0.4
8	20493	0.4	1.43	0.55	0.5			9.0
9	26382		1.43					0.4

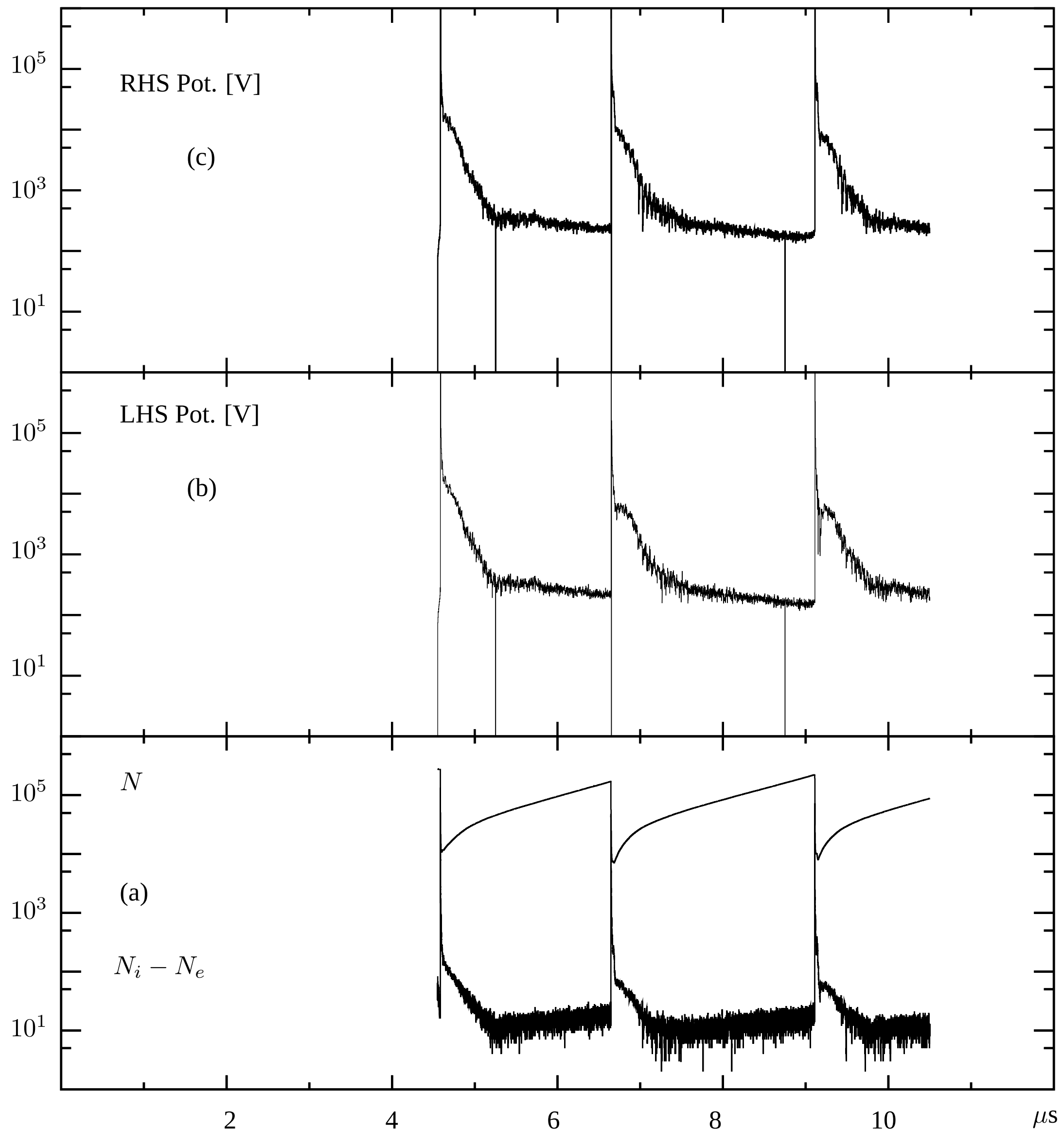

Figure 1: Time variation (a) up: Nunber of 'computer' particles, N; (a) down: difference between 'computer' numbers of ions and electrons, $N_i - N_e$; (b) LHS Potential; (c) RHS Potential.

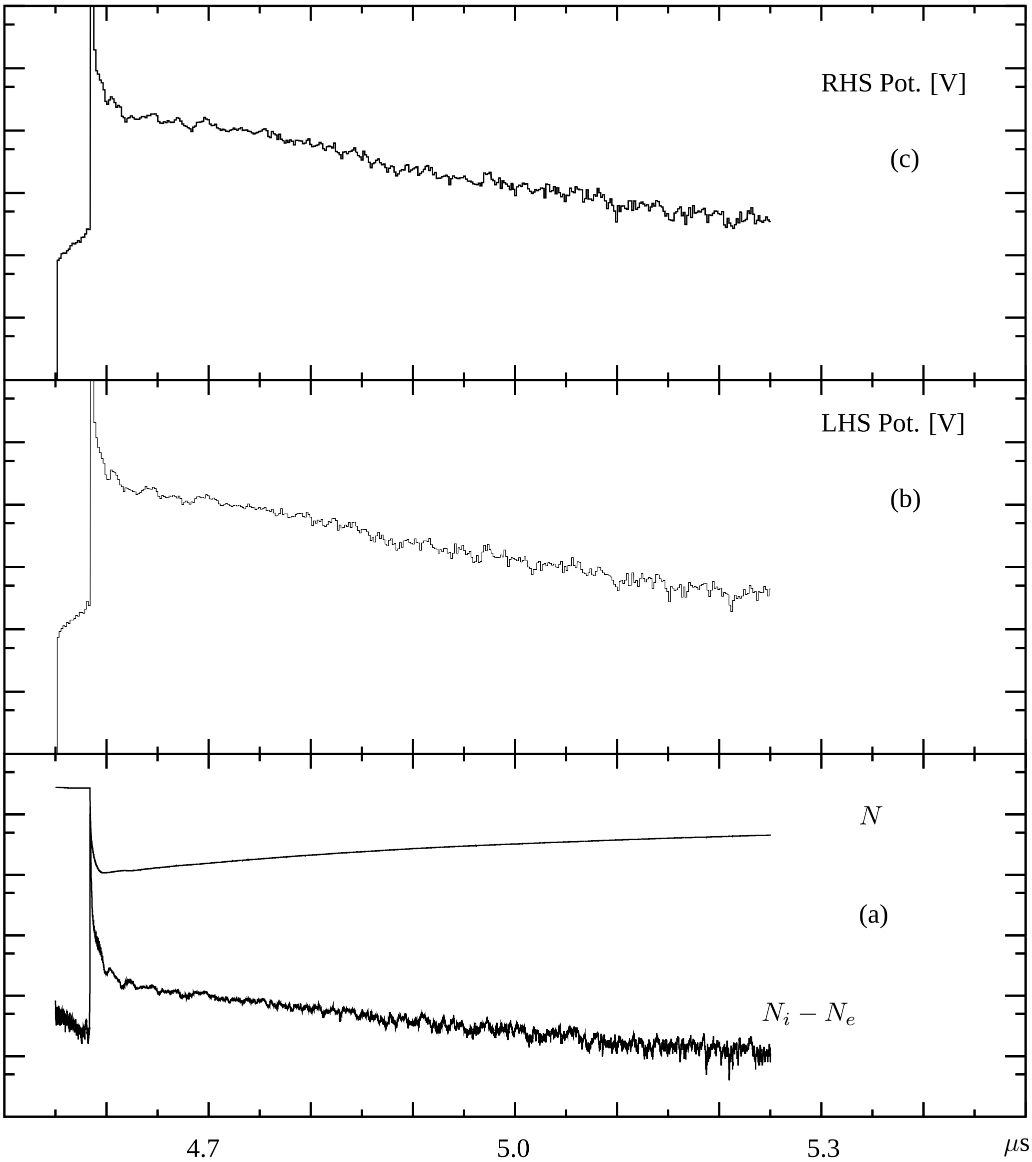

Figure 2: Large scale fragment from Fig. 1.