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Dependence of ELM frequency on pedestal plasma density and temperature

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Abstract: Correlations of ELM frequency with plasma temperature and density at the pedestal have been studied. We have derived an uniform formula from the first thermodynamic principle and Fokker-Plank equation accounting for the engineering factors.
Key words: tokamak, relaxation, ELM, collisions
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1. Thermodynamic description of stationary ELMs. MHD turbulence localized at the edge of plasma enters in stationary state when the loss of power is compensated by the heating. The conservation of energy in a large time scale implies:

$$W_{ped} = \frac{3}{2}\, n\, (T_e + T_i)\, V_{ped} = \text{const} \tag{1}$$

In this scale the volume of the turbulent edge plasma, V_{ped} is constant and the averaged temperature of pedestal ions T_i is approximately equal to that of electrons T_e due to exchange of energy in collisions.

Conductive ELMs are characterized with intensive soft X-radiation and large loss of energy in emission (more than 20%.) The pedestal density is relatively low and remains constant. After each collapse the pedestal plasma is heated in dominating Coulomb collisions. Neglecting the time of collapse (about $200\mu s$) one might expect that the time for recover of ELM, $\tau_{elm} = 1/f_{elm}$, should be equal to the time of heat exchange,$\tau_{i,e}$, where $\tau_{i,e} = \frac{m_i}{2m_e}\tau_e$, and

$$\tau_e = 1.09\, 10^{16} \frac{T_e^{3/2}}{n\, Z\, ln\Lambda} \quad s \tag{2}$$

is the collision time of electrons derived from the Fokker-Planck coefficients (Maxwellian distribution of velocities is assumed).

The expression for τ_e is expected to be valid also for the case of energy loss of a particle beam [1]. Thus for the time of ELM's recover we obtain the following dependence on pedestal plasma temperature and density:

$$\tau_{elm} = 1.2\, 10^{18}\, \frac{T^{1.5}}{n}\; s \tag{3}$$

where T is measured in KeV, n is measured in m^{-3}, and the Coulomb logarithm is 17. For typical ELMs in JET experiments (I_p = 2.5MA, B_T = 2.7T, $P_{NBI} = 16\ MW$) ELM's frequency is $f_{elm} = 35\ Hz$)[2]. That implies $\tau_{elm} = 1/f_{elm} = 0.0286\ s$, which is a little bit less than the corresponding value $\tau_{ped} = 0.03\ s$ calculated with the above formula for the averaged values of recovered pedestal temperature $T = 1.1\ KeV$ and density $n = 4.6\, 10^{19}\, m^{-3}$.

In many cases experimental data [3], [4] reveal a trend to linear dependence

$$f_{elm} = a + b\, n\ Hz, \tag{4}$$

illustrated in Figures 1a,2a,3a. The parameters of (4) for six shots in JET are shown in Table 1. They vary with the configuration of the main engineering parameters presented in the Table. Using (4) we obtain from (3)

$$n = a\,c\frac{T^{3/2}}{b\,c T^{3/2} - 1}. \qquad (5)$$

It represents the relationship between the density n and the pedestal temperature T accounting for the impact of the engineering parameters.

The values of the parameter c are defined from the fit of data (Figures 1b, 2b, 3b). Its deviation from the value $1.2\,10^{18}$ corresponding to pure diffusion transport is a measure of the impact of non diffusion transport.

2. Discussion and Conclusions. These results are obtained on the basis of published data in a limited region of JET experiments. They reveal an apparent violation of ELM frequencies from the Fokker-Plank predictions. It is expressed by the variation of the parameter c (respectively a and b). They vary for the same physical characteristics of pedestal plasma (temperature and density) depending on the engineering conditions. The decrease of c (ruling the time for ELM recover) could be related with the appearance of additional (e.g. convective) transport. In the next 4 figures there is illustrated the correlations of c with particular engineering parameters. Clear hint for increasing convective transport with heating power is seen in Fig.5. It should not be neglected in preparation of ELM scenario for ITER experiments.

Table 1: Experimental conditions (current I, magnetic field B, plasma shape δ, additional heating P_{inp}) for 6 shots with JET and the corresponding parameters in the approximation formulae: a, b, (eq. 4), c (eq. 5)

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	7	-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

More precise estimation of the impact of a particular engineering factor could be made if one has in disposal enough data selected for the same experimental conditions.

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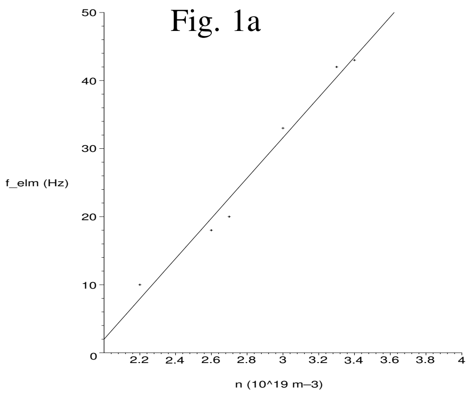
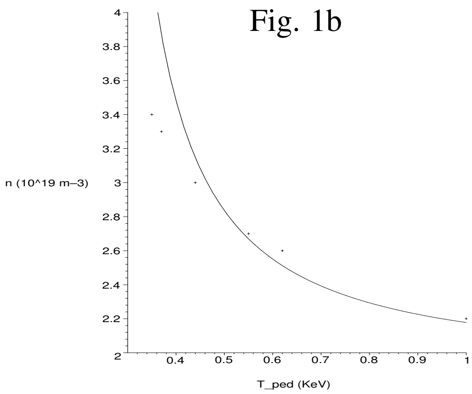
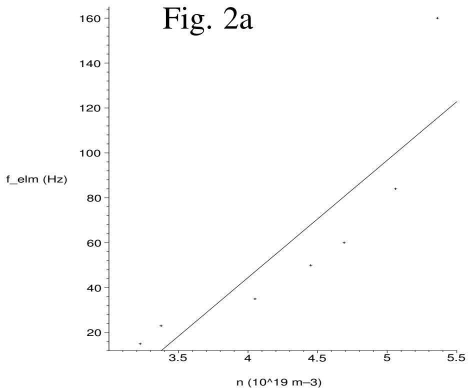
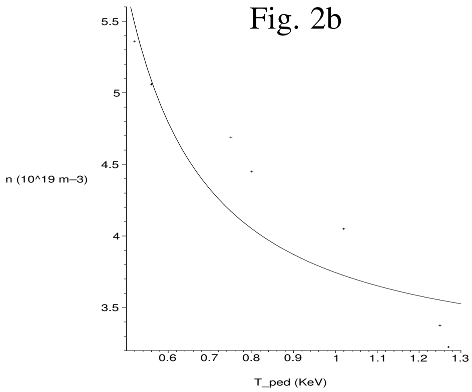
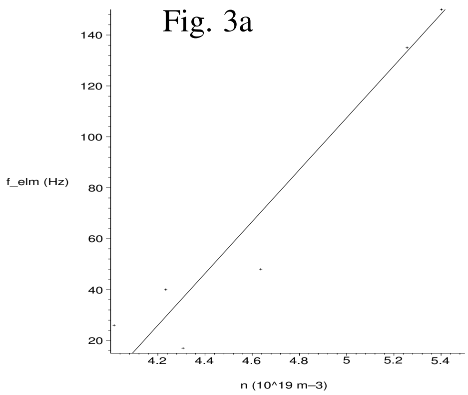
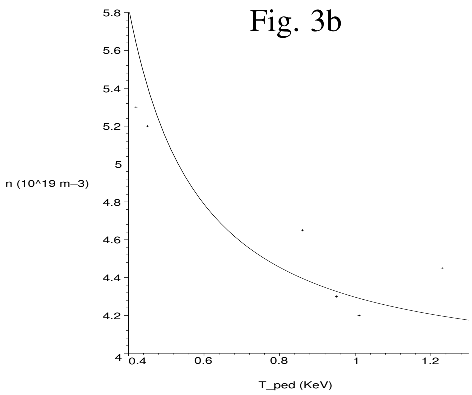






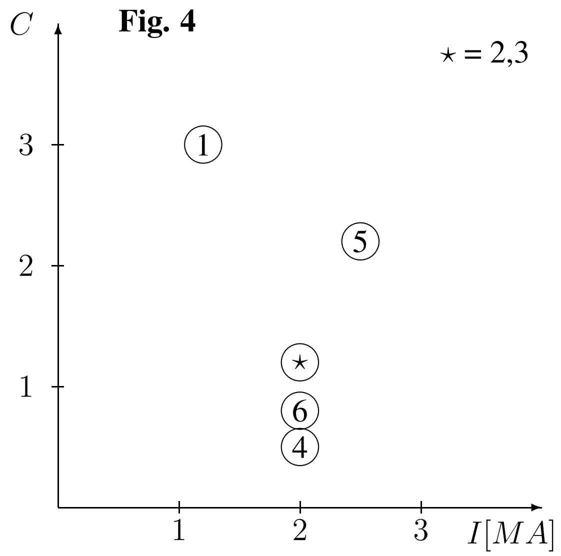


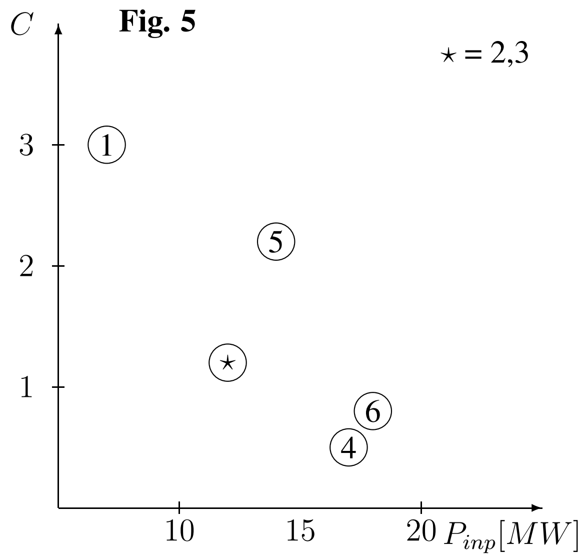


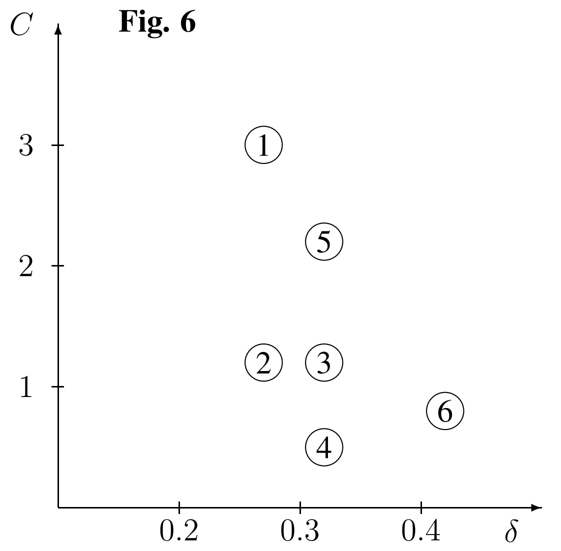


Figures 1a–3a: JET data for the dependence of ELM frequency on pedestal plasma density fitted with the linear dependence, eq.4. The parameters a, b and the experimental conditions are in Table 1, rows 1–3 correspondingly,

Figures 1b–3b: Comparison of JET data for the correlation between pedestal plasma density and temperature with the functional dependence, eq.5. The approximation parameters and the experimental conditions are put in Table 1, rows 1–3 correspondingly.







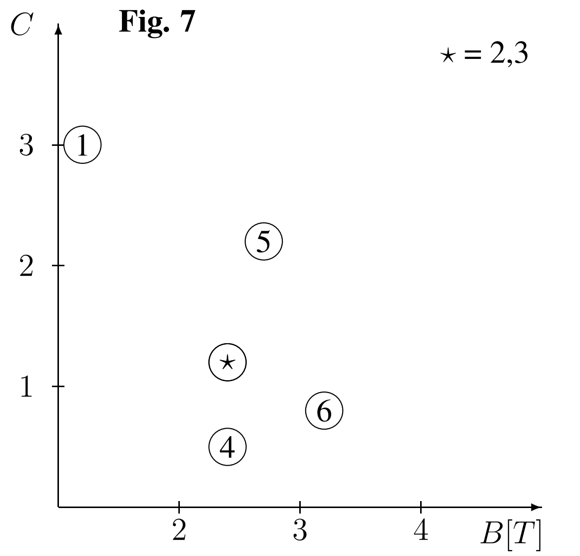


Fig.4 Variation of the parameter c with plasma current I.
Fig.5 Variation of the parameter c with the heating power P_{inp}.
Fig.6 Variation of the parameter c with plasma shape δ.
Fig.7 Variation of the parameter c with the magnetic field B.