A POSSIBLE PHYSICAL EXPLANATION FOR TYPE III ELMs IN TOKAMAKS.

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ABSTRACT

The resistive interchange instability accompanied by magnetic flutter is considered as a possible candidate for the onset and development of Type III ELMs. The flutter provides the resistive driver for the interchange instability. The proposed theory allows one to derive the dependencies of the upper boundary for Type III ELMs on Te and ne, as well as the scaling of the amplitude and the frequency of these oscillations, which are in agreement with the experimental results.

1. INTRODUCTION

The suppression of Alfven-Drift instability (**AD**) at a threshold β in the edge region has been proposed as a possible trigger mechanism for the L-H transition [1]. This theory predicts a scaling for the edge pedestal temperature versus density in good agreement with the experimental results from many tokamaks [2]. In this paper we extend this approach to explain the Type III ELM phenomena and the role of the electrical field in subsequent stages of the L-H transition. The resistive interchange instability accompanied by magnetic flutter (**RIF**) (the flutter gives rise to the diffusion of the electrons by small scale, less than the ion gyroradius, electromagnetic perturbations) is considered as a possible candidate for the onset and development of the Type III ELMs. The flutter provides the resistive driver for the interchange instability. Before the L-H transition the resistive interchange mode is superseded by strong thermal conductivity due to Alfven drift turbulence. After the transition, with the Alfven drift transport suppressed, the resistive interchange instability emerges as the dominant phenomena in form of Type III ELMs. With the steepening of the pressure gradient the radial electrical field just inside the separatrix increases. If this electrical field becomes sufficiently strong it can stabilise the **RIF**. This condition gives the upper boundary for the Type III ELMs in the n_e-Te diagram. After stabilisation of the Type III ELMs the gradients near the edge increase further. The plasma then evolves until the ideal ballooning boundary (Type I ELMs) is reached. The proposed theory allows one to derive a scaling for the frequency of the Type III ELMs, the dependencies of the upper boundary for Type III ELMs on Te and ne, as well as the scaling of the amplitude of the Type III ELMs oscillation. A comparison of the theoretical predictions with the tokamak experimental data has been made and the details of this are given in this paper.

2. DISPERSION EQUATION AND DIMENSIONALESS PARAMETERS.

The dimensional approach of Kadomtsev and Connor-Taylor is the main instrument of the following analysis. **The dispersion relation reflects the conservation laws of the system and strongly restricts the number of the dimensionless independent parameters.** The dispersion equation for the MHD resistive interchange modes with electron viscosity (flutter) can be written symbolically in the form:

$$k_\perp^2\omega+\frac{\omega_{gi}^2k_\theta^2}{\omega+ik_\perp^2(\chi_{AD}+\chi_{RIF})}+\frac{\omega_{ge}^2k_\theta^2}{\omega+ik_\perp^2(\chi_{AD}+\chi_{RIF})+ik_{//}^2\chi_{//e}}=\frac{k_\perp^2k_{//}^2c_A^2}{\omega+k_\perp^2\delta^2(\omega+i(\nu_{ei}+\nu_F))} \quad (1)$$

Here $k_\perp$, k_θ, $k_{//}$ - are the transverse, poloidal and longitudinal wave numbers; $\omega^2_{g,\alpha} = (2/n_0 R)\partial P_{0\alpha}/\partial r$, ($P_{0\alpha} = n_0 T_{0\alpha}, \alpha = i,e$) - are the ion and electron curvature drift frequencies; χ_{AD} and χ_{RIF} are the anomalous transport coefficients for **A**lfven-**D**rift (**AD**) instability and **R**esistive **I**nterchange **F**lutter (**RIF**) instability; $\chi_{//e}$ - is the classical parallel thermal conduction coefficient; $c_A = \sqrt{B_0^2 / 4\pi n_0 M}$ - is the Alfven frequency and $\delta = \sqrt{4\pi e^2 n_0 / m_e}$ - is the collisional skin depth; ν_{ei} - is the electron-ion collision frequency and

$$\nu_F = k_\perp^2 \delta^2 \cdot \nu_{0F}, \quad (\nu_{0F} = \sqrt{(\nu_{Te}/qR)^2 + (\nu_{ei})^2}) \tag{2}$$

is the flutter frequency [3, 4]

Comparing the main terms in (1) we have estimation:

$$\omega \approx \frac{\omega^2_{gi}(k_\theta^2 / k_\perp^2)}{\omega} \approx i \frac{k_{//}^2 c_A^2}{k_\perp^2 \delta^2 \nu_F} \tag{3}$$

This problem contains the following basic dimensionless parameters:

$$\beta = 4\pi P_0 / B_0^2, \ \ \bar{\beta} = (M/m)^{3/2} \cdot \beta \cdot s^2 / q, \ \bar{\rho} = \rho_s / R, \quad \bar{x}_0 = x_0 / \rho_s,$$
$$s = (r/q)\cdot(dq/dr), \ \bar{k} = k_\perp \rho_s \quad \bar{\gamma} = \gamma \cdot x_0 / c_s \quad \bar{\chi} = (x_0 / c_s \rho_s)\cdot \chi_\perp .$$

If we take into accounts the Spitzer resistively only we have only two important dimensionless parameters: $\bar{\rho} = \rho_s / R$ and λ_e/qR. This does not give the proper combination in the n – T_e diagram for the Type III ELM threshold. The flutter adds the key new parameter β (see final result (8)). From (3) we can derived the expression for the dimensionless growth rate $\bar{\gamma}$ and turbulent transport coefficient $\bar{\chi} = (\bar{\gamma} / \bar{k}^2)_{\max}$ in terms of the width of the instability localisation $\bar{x}_0$:

$$\bar{\gamma} = \bar{\rho}^{1/2} \bar{x}_0^{1/2}, \qquad \bar{\chi} = (\bar{x}_0 \cdot \bar{\rho})^{1/4} / [\bar{\beta} \cdot \bar{\lambda}]^{1/2}, \tag{4}$$

where $\bar{\lambda} = \left[c_F \cdot \sqrt{1 + ((c_\nu \cdot qR)/\lambda_e)^2}\right]^{-1}$ is the dimensionless version of the inverse flutter frequency ν_{0F} (2) (we insert here two trial constants c_F and c_ν). The expression for $\bar{x}_0$ follows from hypothesise that the balance of the transverse $\chi_\perp$ and longitudinal loss $\tau = c_\tau \cdot L / qR$ defines the characteristic gradient $x_0 = (P_0 / dP_0 / dr)^{-1}$ near the edge:

$$x_0^2 = \chi_\perp \cdot \tau, \tag{5}$$

here $L \propto q \cdot R$ is the connection length and c_F, c_ν, c_τ are trial constants.

3. THE STABILISATION OF RIF BY THE PLASMA SHEAR FLOW.

If the shear of the flow due to electrical field exceeds the growth rate the instability is stabilised $d(V_E)/dr > \gamma$. Taking into account this condition the total growth rate can be written as

$$\gamma = \omega_{Bi} \cdot (\bar{\gamma} - 1/\bar{x}_0)/\bar{x}_0 . \tag{6}$$

The Type III ELMs oscillations are characterised by two different time intervals: the width of the spike, which inversely proportional to the grout rate $\bar{\gamma}$ and the distance between spikes, which characterises the ELMs frequency.

For the last one the theory predicts the expression:

$$f_{ELMIII} = \gamma / \sqrt{\gamma \cdot \tau} = \gamma / (x_0 \cdot k_\perp), \qquad (7)$$

See Fig.1, where is illustrative picture. f_{ELMIII} is typically ten times less than the growth rate. Using the relation (5) we can exclude the value x_0 from the expression (4), (5) and (6) and finally write them in terms of the density and the temperature. Stability condition γ =0 (see (6)), which defines n-T diagram can be written in terms of the basic parameters as:

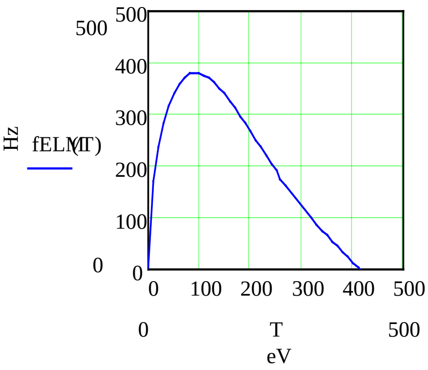


Fig.1

$$\bar{\beta} \cdot \bar{\lambda} > (c_F \cdot c_\tau^{\ 2} \cdot q^2) \cdot (\bar{\rho})^{1/3}. \qquad (8)$$

This gives the following asymptotically correct scaling for the temperature:

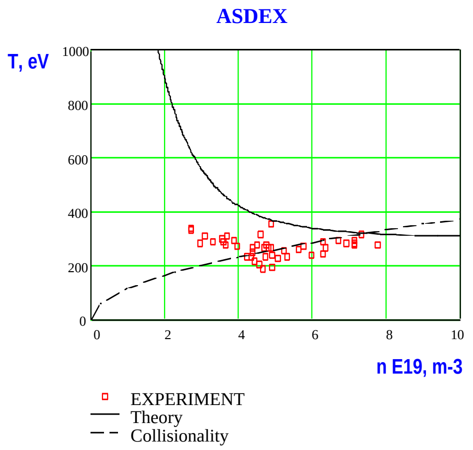
$$T_{0cr} \propto (c_\tau^{\ 2} \cdot c_F \cdot c_\nu)^{6/17} \frac{q^{24/17} R^{4/17} B_0^{10/17}}{A^{8/17} s^{12/17}} \qquad (\text{for } \lambda_e < c_\nu q R)$$

and

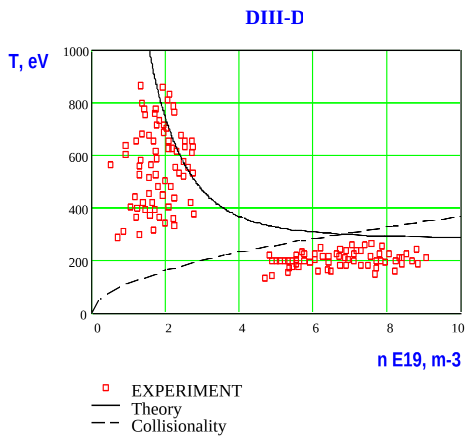
$$T_{0cr} \propto (c_\tau^{\ 2} \cdot c_F)^{6/5} \frac{q^{18/5} R^{-2/5} B_0^2}{A^{8/5} s^{12/5} n_0^{6/5}} \qquad (\text{for } \lambda_e > c_\nu q R) \qquad (9)$$

The comparison of the theory with the experimental data on tokamaks is given bellow.

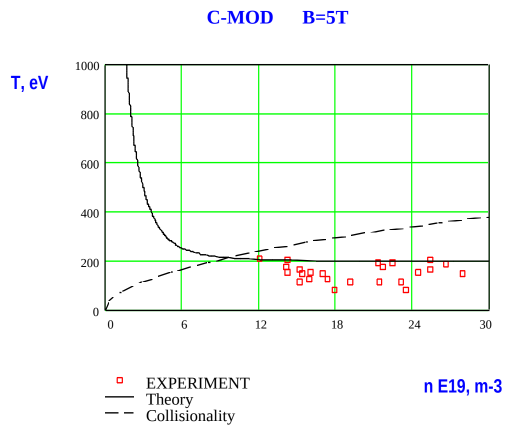
4. THE COMPARISON WITH THE EXPERIMENT



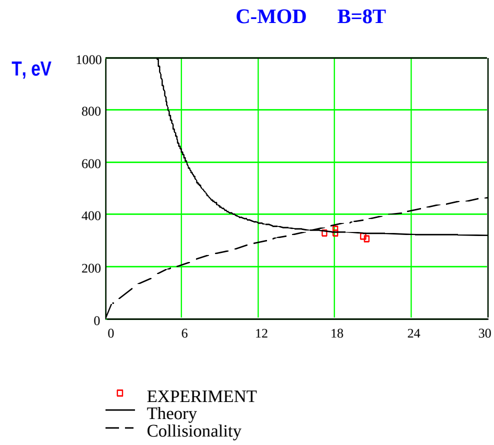
Data adapted from M.Kaufmann et al., 1997
B=2.5T, I=1MA, R=1.7m, q=3.9, s=3



Data adapted from T.Osborn et al., 1996
B=2.1T,I=1.5MA,R=1.7m,q=3.97,s=3



Data adapted from A.Hubbard et al., 1996
B=5.4T, I=1MA, R=0.69m,q=3.5,s=6



Data adapted from A.Hubbard et al., 1996
B=8T, I=1MA, R=0.68m, q=5.3, s=7

$$(c_F = 15.0,\ c_\nu = 4.0,\ c_\tau = 3.5*(3.97/q))$$

5. CONCLUSIONS

The RIF instability is identified as a cause of the Type III ELMs because:

- *it predicts the upper temperature scaling on plasma parameters in agreement with experimental data from many tokamaks;*
- *it predicts the dropping of the dependence of the ELMs frequency with the pedestal temperature (power);*
- *Interchange Resistive instability develops in a " bad curvature" side which explains why in experiment the type III ELMs are mainly loading power on the outer target.*

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