MHD STABILITY OF THE EDGE PLASMA IN ALCATOR C-MOD

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Operational range of EDA H mode.

Two types of H-modes are generally observed in Alcator C-Mod – ELM free and EDA. ELM-free H-mode is characterized by the absence of any kind of edge pedestal relaxation mechanisms and, therefore, by an enhanced impurity confinement. Both plasma density and radiated power rise rapidly during an ELM-free H-mode and it terminates in radiative collapse. In contrast, EDA H-mode usually exists for as long as the auxiliary heating is applied. It is a steady state regime with constant line average density and radiated power, no significant impurity accumulation throughout the discharge, and energy confinement comparable to that of ELM-free H-mode.

It was shown previously [1] that in EDA H-mode the enhanced impurity transport across the edge barrier is provided by a quasicoherent electromagnetic mode (QC mode) localized at the pedestal region. The QC mode is clearly seen in EDA as a narrow band ($\Delta f \sim 10$ kHz) density fluctuations at ~ 100 kHz. In contrast, ELM-free H-mode is characterized by decreasing level of fluctuation relative to L-mode. It was shown in [1] that the transition to EDA regime occurs at q_{95} (q at 95% flux surface) of about 3.5 and higher. At lower values of q_{95} only ELM-free regime can be obtained. The EDA/ELM-free boundary depends also on plasma shape, with EDA occurring in the range of triangularities between 0.35 and 0.5. In this paper we present the results obtained at a fixed plasma shape and explore the dependence of EDA/ELM-free boundary on T_e and n_e pedestal parameters. We found that at line average target densities above n_{l0} = 6e19 m^{-2} EDA H-modes are obtained in high q discharges with weak dependence of both core and pedestal density on target density. This is consistent with the general observation that H-mode density is controlled mainly by plasma current and does not strongly depend on any other plasma parameters. However, at n_{l0} < 6e19 m^{-2} very low density pedestal is formed after the L-H transition and, since the heating power remains at the same level, high temperature pedestal develops, leading to a dramatic drop in edge collisionality. No QC mode is observed in this regime and the obtained H-mode is clearly ELM-free. It should be noted that the maximum edge pressure gradients in ELM-free and EDA regimes are similar in all operational regimes (both low and high q discharges). This suggests that the appearance of the quasicoherent mode in EDA regime can not be explained in the framework of ideal ballooning theory and requires taking into account the finite resistivity effects. The found correlation of EDA/ELM-free regimes with edge collisionality and q is summarized in Fig. 1. The collisionality on top of the pedestal is calculated using Thomson scattering electron temperature and density profiles [2]. The EDA regime generally occurs at high collisionality, high q values, while ELM-free H-mode can occur in either high q/low ν^* or low q discharges with any value of edge collisionality.

The upper boundary of the EDA operation range is observed in the discharges with high input power (P_{RF}>3 MW) and edge pressure gradients at or above 1e7 Pa/m. Under these conditions small high frequency ELMs replace the QC mode. The quasicoherent mode in this regime virtually disappears, turning into a low frequency (~ 40 kHz) broadband turbulence. In these plasmas large edge pressure gradient drives significant edge bootstrap current which can, in turn, drive the peeling/ballooning modes exhibiting themselves as grassy ELMs. This model is considered in details in the following section of the paper. The QC mode is being replaced by grassy ELMs when pedestal temperatures reaches values of 400 - 450 eV and higher and pressure gradient at the edge increases to 1 – 1.5e7 Pa/m. If we calculate the ideal infinite n ballooning stability limit in approximation of zero bootstrap current at the edge, the edge pressure gradient normalized to the limit will be α/α_c~.1.5 or higher. The transition from EDA to ELMy regime is clearly seen in Fig.2 that shows normalized edge pressure gradient vs pedestal temperature for various types of H modes.

Ideal MHD stability.

To identify the role of MHD stability in limiting edge gradients, formation of EDA and ELMs ideal MHD stability analysis was performed for infinite to intermediate n modes. Infinite n ideal ballooning stability of the ELM-free and EDA discharges for a range of edge parameters was analyzed using the BALOO [3] code. Intermediate n coupled peeling/ballooning modes were evaluated with ELITE code [4]. The equilibria for the stability analysis were obtained using kinetic EFIT and, therefore, are based on measured edge pressure profiles. Pressure gradient driven bootstrap current plays an important role in edge stability. The equilibria used in our analysis were calculated with three models for the edge current – collisionless, that calculates edge current as a sum of ohmic current, based on neoclassical resistivity, and bootstrap current from Hirshman model [5], collisional, using neoclassical model from [6] to calculates effects of edge collisionality on magnitude of the bootstrap current, and the edge current profile calculated with no bootstrap contribution, thus assuming total suppression of the bootstrap current by high collisionality. It was shown that for all observed edge pressure gradients in C-Mod the edge is stable for infinite n ideal ballooning mode if the bootstrap current, even strongly reduced by edge collisionality, is taken into account. Results of intermediate n MHD stability analysis are shown in Figs. 3 and 4. Fig. 3 illustrates the strong dependence of the MHD growth rate on the edge current. Growth rates for both low power, low edge gradient ($\alpha/\alpha_c \approx 1$) EDA (blue) and high power ELMy (red) shots are shown. Note that, for the expected collisional bootstrap current, the low power EDA case is found to be stable, while the higher power, higher ∇P ELMy shot is MHD unstable, with intermediate n modes (20<n<50) dominant, and an n=30 growth rate of $\gamma/\omega_A = 0.05$. Low q ELM-free shots have also been studied, and found to be unstable only to very weak, strongly localized MHD modes, even at large ∇P^{ped} (α/α_c =1.5). In Fig. 4 the radial eigenmode structure of a localized peeling mode from an ELM-free discharge is contrasted to the broader structure of the much stronger peeling/ballooning mode in an ELMing discharge. The contrast in intermediate n stability between ELMing and ELM free discharges appears consistent with a model of ELMs as intermediate n peeling/ballooning modes [4]."

References

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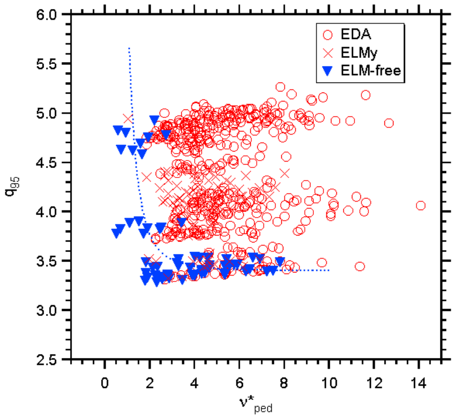

Fig. 1. QC mode (EDA) exists in high edge q, high collisionality discharges. Lower ν* and/or lower q_5 lead to ELM-free H mode

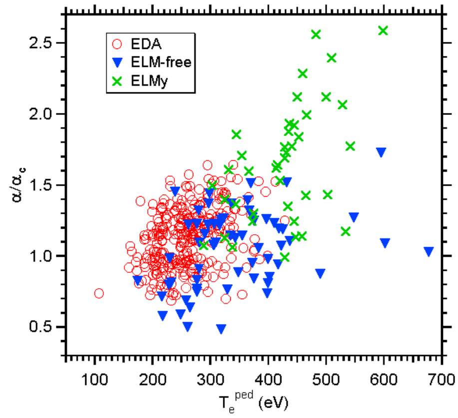

Fig.2 Small ELMs replace QC mode in discharges with $\alpha/\alpha_c > 1.7$ and T_e^{ped}>450 eV. ELM-free regime has the similar edge gradient as EDA

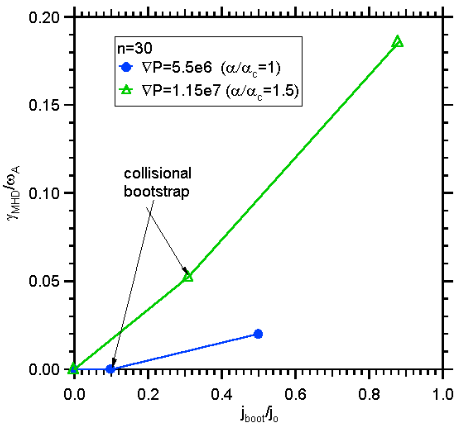

Fig. 3. Intermediate n growth rate is much higher in ELMing discharge than in EDA. EDA mode is stable with expected bootstrap current

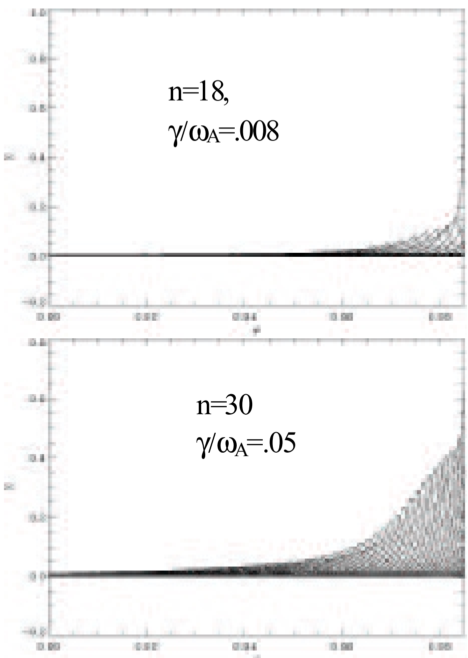

Fig. 4. Mode structure for ELM-free (top) and ELMy (bottom) regimes with similar edge pressure gradient α/α_c=1.5. Pure peeling structure localized at the LCFS in ELM-free as opposed to extended peeling/ballooning mode with much higher growth rate in ELMy