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Density Limit Disruption Induced by Core-localized Alfvenic Ion Temperature Gradient Instabilities on HL-2A

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Plasma disruptions are large catastrophic events in tokamak nuclear fusion burning plasmas. Disruptions result in a sudden confinement loss, so that heat and particles are rapidly expelled to the device wall. Disruptions can abruptly destroy the plasma facing components, and terminate the fusion reaction. Disruption issues are of central importance to future fusion reactors such as ITER. Meanwhile, high plasma density (*ne*) is essential for the access to high fusion gain since the fusion power density scales as ne^2. However, there is a limit (known as Greenwald density limit) for tokamak high density discharges. The Greenwald density limit is an empirical limit for the achievable line-averaged plasma density on experiments, namely $ne_G=I_p/\pi a^2$, where ne_G is the line-averaged plasma density in units of $10^{20}m^{-3}$, I_p the plasma current in *MA* and *a* the minor radius in *m*. Generally, when the Greenwald density is reached, the bulk plasma frequently disrupts as well as the discharge halts, namely so called density limit disruptions. Density limit disruptions have been an active area of research for decades. Many previous experimental results indicate that the density limit disruption occurrence is correlated to the plasma edge cooling, multifaceted asymmetric radiation from edge (MARFE), current channel shrinkage, macroscopic magnetohydrodynamics (MHD) activities (mainly tearing modes), edge turbulence, and so forth. These results indicate that density limit disruptions originate from the plasma edge region. Some experimental results also suggest the density limit can be exceeded by the plasma core fuelling, edge pumping, or modification of particle transport lead to peaked density profiles. In the light of them, many theories are proposed to unravel the mechanism of density limit disruptions, however, the underlying physics is not yet fully covered and understood.

Recently, the high density experiments with $ne/ne_G\sim1$ had been carried out using the conventional gas-puff fuelling method in HL-2A NBI and Ohmically heated plasmas. It is found for the first time that there are multiple-branch MHD instabilities in the core plasmas while $ne/ne_G>0.85$. The experiment and simulation analysis suggests that the core-localized magnetohydrodynamics (MHD) activities belong to Alfvenic ion temperature gradient (AITG) modes or kinetic ballooning modes (KBMs), and on experiment firstly, it is discovered that they trigger the minor or major disruption of bulk plasmas while the density is peaked. The time evolution of line-averaged density indicates that AITG/KBM instabilities induce particle transport outward in radial direction, and accompanied by the evolution of these instabilities, disruptions appear. The experimental results suggest that AITG/KBM instabilities are excited with core *Ti* and *ne* increasing, therewith the core Ti drops and Ti-profiles collapse, and large-radius ITBs form in this process. It indicates that these instabilities induce strong ion heat transport. These AITG/KBM instabilities are driven in sequence or simultaneously from high-n to low-n at the q=1-2 surface localization, and induce global ballistic transport outward. The transport characters are domino and avalanche in radial direction. A new physics picture density limit disruption is found: 1) fueling and ne peaking; 2) edge cooling and core AITG/KBMs unstable; 3) core-ne flatting, m/n=2/1 tearing mode growth and disruption, so that the system is positive feedback and unstable. The density limit disruption is global from core and edge plasma, and electromagnetic. The experimental results challenge all theory models of the density limit disruption at present. These instabilities can be used as artificial intelligence (AI) disruption predictors, and tens of milliseconds ahead. These new findings are of great importance to figure out and understand the origin of the density limit.

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