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Radiation power profiles in the plasma with the Dynamic Ergodic Divertor on TEXTOR

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Abstract

The two-dimensional profile of the radiation distribution and the total radiation power in the plasma with the dynamic ergodic divertor (DED) have been measured by four bolometric cameras with the tomographic techniques on TEXTOR. An increase in the total radiated power after the onset of the m/n=2/1 mode is less than 5%, while a remarkable increase from 40% to 60% in the ratio of total radiated power over total input power, P_{rad}/P_{total}, has been observed when the m/n=3/1 tearing mode existed in the plasma edge due to the DED perturbation field. A strong influence of the DC and AC 1kHz DED on the formation of the multifaceted asymmetric radiation from the edge (MARFE) has been observed in plasmas with Ohmic heating and NBI, respectively.

Introduction

With MARFEs, one type of the density limit has been observed in several tokamaks and stellerators. They are usually located at the high field side (HFS) near the inner wall in limiter tokamaks, or near the X-point with the divertor configuration. The development of MARFEs may results in plasma detachment or disruptions. The results from both of experimental observation and theoretical models show that the interaction between plasma and wall together with the working gas neutral's properties play the role in the thermal instabilities at the plasma edge [1-4]. On TEXTOR, a significant extension of the density limit by a factor of 1.7 compared to the Greenwald density-limit, n_e^{GW}, has been observed with fresh boronization or fresh siliconization [2]. Complete suppression of the MARFE has been achieved by controlled displacement of the plasma column to the low-field-side[3]. However, all these experiments are based on the reduction of the local recycling and impurity release at the inner wall. Since MARFEs have a strong dependence on the poloidal angle, it remains an open question whether MARFEs could be avoided by uniformization of the recycling at plasma edge.

Recently, a DED has been installed on the TEXTOR at HFS. First results on the influences of the DED perturbation field on the radiation profile and density limit are presented within this paper.

Experimental setup

In the present experiments, the DED has been operated in the m/n=3/1 mode, where m, n are the mode numbers of magnetic perturbations in poloidal and toroidal direction. There are two operation regimes of the DED on TEXTOR: DC and AC with frequencies up to 10 kHz. The two-dimensional radiation profile and the total radiated power in TEXTOR are measured using four bolomertic cameras with low-noise, miniaturized, ac-excited metal foil resistor bolometers. Tomographic techniques have been used to reconstruct the two-dimensional radiation profiles with a spatial resolution of ~4cm and a temporal resolution of ~10ms[5]. On TEXTOR, the plasma electron temperature, T_e, and density, n_e, profiles are measured by multi-channel electron cyclotron emission (ECE)[6] and HCN interferometry

[7], respectively. The time evolution of spectral lines from different impurities (i.e. C and O) and ionisation stages was monitored using a fast VUV overview spectrometer[8] with radial sightlines near the horizontal mid-plane. MHD behaviour is analyzed via the signals measured by soft x-ray pin-diode cameras and sets of fast Mirnov-coils.

The influences of the DED perturbation field on the radiation profile

Figure 1 (a) and (b) show the total input power and the total radiated power, respectively, for a plasma with DC DED. In these experiments, the plasma has been heated by neutral beam injection (NBI) with input power of 0.4MW; a toroidal plasma current, Ip=300 kA, and a toroidal magnetic field, Bt=2.25T. When the DED coil current (I_{DED}) reaches 0.7kA, the onset of an m/n=2/1 tearing mode generated by the perturbation field is observed by the soft x-ray cameras [9]. Both, the central line integrated electron density and the central electron temperature suddenly drop. However, at the plasma edge the electron density increases whereas the electron temperature decreases. Just after this event, the gas-puffing feed back system starts to add fuel trying to maintain a constant central line integrated electron density. Nevertheless, the increase in total radiated power measured by bolometry after the onset of the m/n=2/1 is less than 5%. No significant change of impurity radiation (such as C and O) is observed by the fast VUV spectrometers. When the DED coil current ramped up and reaches a second critical value (about 2.3kA), a remarkable increase in radiated power around the plasma edge (ρ>0.7) has been observed. When the DED current reaches 3.75kA the change in total radiation power increases to 60%. The results from MHD analysis shows a locking of the m/n=3/1 mode when the DED reaches the second critical value. A high radiation spot is formed at the high field side near the divertor target plates covering the helical coils, when the I_{DED} ramped up to 3.75kA. The location of this high radiation spot concedes with the strike zone of ergodic divertor (ED) as calculated. The effect on the total radiation power by DED operated in AC mode with frequencies above 1kHz and a current below 2kA is small.

The influences of the DED perturbation field on the density limit

The investigation of the influence of the DED perturbation field on the density limit has been done for both, Ohmic and NBI heated plasmas. Here, the magnetic signal was used instead of edge interferometer density signals for the position feed-back control in order to avoid an outward shift of plasma in response to the generation of a MARFE.

In an Ohmic discharge without DED, no MARFE is observed in the plasma until the radiation collapse happens, i.e. the radiation power equals the total input power. A clear detachment appeared when the electron density approaches n_e^{GW} . However, when the DC DED was applied to the plasma, the MARFE is observed at the HFS with a toroidally symmetric distribution. MARFE appears earlier when I_{DED} increased from 0.6kA to 1.0kA and 3.75kA, respectively. For the discharges with AC 1kHz of DED, no MARFEs are observed, even if I_{DED} is increased to 2kA. When a 2/1 tearing mode is created by the DED perturbation field, a reduction of the density limit due to radiation collapse is observed, whereas there is almost no change in the density limit for the discharge with I_{DED} below the threshold of the 2/1 tearing mode onset.

In plasmas with full power NBI (1.3MW) in co-current direction, the maximum electron density achieved was usually limited by the MARFEs. Figure 2(a) and (b) show the time evolution of the electron density and total radiation power for the discharges with DC (blue) and AC 1kHz DED (red). In these experiments, the DED coil current was ramped up from 0.7s to 0.8s, then keeping it constant up to 5.8s, and ramping it down to zero at 5.9s. The duration of NBI is from 0.5s to 6.5s. Because of a problem in one of the two gas puffing systems during these experiments, the ramp-up rate of n_e could not exceed than $0.6\text{x}10^{19}\ \text{m}^{-3}\ \text{s}^{-1}$ even with the puffing valve completely opened. In the DC case, I_{DED} was set to 0.6kA which is just blow the 2/1 mode threshold. A sudden drop in n_e and P_{rad} at about 4.5s, 5.3s and 5.6s is due to accidentally losing the heating beam. At 5.88s, when the I_{DED} was ramped down to 0.12kA, a MARFE is generated near the inner wall. The density limit reached is $4.8\text{x}10^{19}\text{m}^{-3}$, which is 1.07 times n_e^{GW}. A sudden increase in P_{rad}, and decrease in n_e due to MARFEs have been observed. In the discharge with AC 1kHz DED, I_{DED} is 0.85kA, and no 2/1 mode is observed in the plasma. The electron density was ramped up to $5.0\text{x}10^{19}\text{m}^{-3}$ (1.11 times n_e^{GW}) during the DED phase as seen in Fig. 2(a). Just after switching off of the DED, a MARFE was generated at t=5.95s. The two-dimensional radiation profiles measured in the plasma with DC DED show a high recycling spot at the HFS which is not present in the AC case. This might be due to the smearing effect by a quick shifting of the strike zones on the divertor plate at HFS, since the rotation velocity of 1kHz DED in toroidal direction is ~$0.81\text{x}10^{6}$cm/s, which is comparable with the neutral impurity velocity (10^5-10^6cm/s). A modulated H_α line emission has been observed at HFS in the plasma with AC 1kHz DED, I_{DED}=0.85kA.

Summary

The influences of the DED perturbation field on the radiation profile and density limits have been investigated. A remarkable increase of 40% to 60% in P_{rad}/P_{total} has been observed when the m/n=3/1 tearing mode is created in the plasma edge by the DED perturbation field. A strong radiation spot at the strike zone of ED near the inner wall has been observed. The preliminary results indicates that the MARFE could be avoided by using the AC operation of the DED, because of the smearing effect on the recycling of the main particles, i.e. the balance of the neutral influx and plasma outflow, at the HFS.

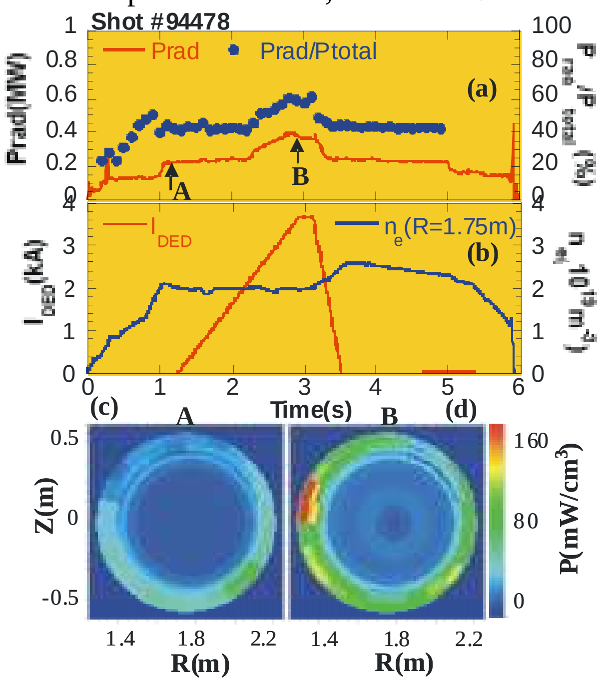

Figure 1 The time trace of (a) the total radiation power (red), the ratio of the total radiation power over the total input power (closed circle); (b) the line-averaged central density (blue) and current of DED coil #1 measured in the plasma with DC. (c) and (d) show the 2-D radiation profiles at 1.1s and 2.9s, respectively.

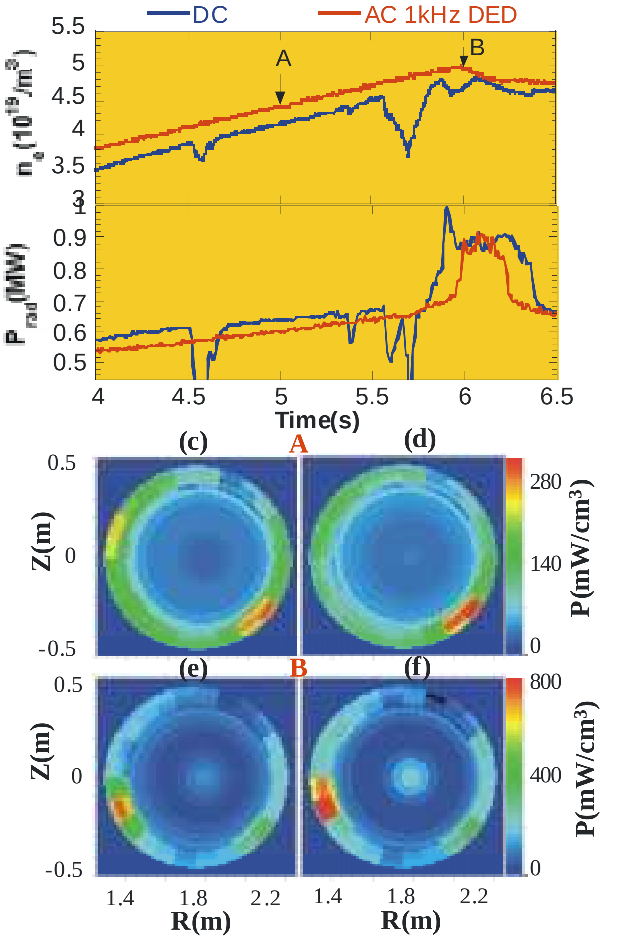

Figure 2 the time trace of (a) the line-averaged central density and (b) the total radiated power measured for the plasmas with DC (blue) and AC 1kHz DED (red), respectively. The 2-D radiation profiles measured at time (c, d) 5.0s and (e, f) 6.0s are plotted for DC (c, e) and AC 1kHz DED (d, f), respectively. The I_{DED} are started from 0.7s and ramp-down from 5.8s to 5.9s in both static (I_{DED}=0.6kA) and AC 1kHz (I_{DED}=0.85kA) DED discharges. A MARFE appeared at a time just after switch-off DED in both cases. The high radiation spot at the low right side is due to high recycling near the ALT limiter on TEXTOR.

References

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