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Radiation belts in the Wendelstein-7AS stellarator

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Abstract

At high plasma density we find two types of radiation belts at the edge of the Wendelstein-7AS stellarator. The first one is observed in the inboard scrape-off layer (SOL) when the edge plasma is detached. It seems to be specific to the stellarator. The second one is found on closed flux surfaces and resembles the Marfe phenomenon known from tokamaks. They are experimentally characterized and modeling calculations are presented.

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1. Introduction

The installation of the island divertor in the Wendelstein-7AS (W7-AS) stellarator allowed access to a new operation regime. In the high density H-mode (HDH) very high line-averaged densities (up to $4 \times 10^{20}\ \mathrm{m}^{-3}$) were quasi-stationary maintained over many tens energy confinement times [1]. In discharges close to the density limit the edge plasma cools down and the plasma radiation detaches from the divertor target plates [2]. Detachment was also detected by a drop of the ion saturation current and the H_α emission in the divertor plasma [3]. These features are very typical also for the detachment process in tokamaks [4]. In this article we describe another observation which seems to be specific for the stellarator edge plasma: the formation of a toroidal carbon radiation belt in the inboard scrape-off layer (SOL).

Radiation belts are also observed in tokamaks. They are the result of a radiative condensation phenomenon on closed flux surfaces (Marfe) [5]. Such kind of radiation belt occurs also in the stellarator W7-AS. As a consequence, the confined energy is degraded up to 50%. In this way Marfes form a density limit in the stellarator [6]. We characterize both types of radiation belts and discuss the physical mechanisms.

2. Experimental

Fig. 1 shows the time traces of discharge #54470. We distinguish two phases. The density is rapidly ramped-up so that the plasma is at the density limit in the first phase (from 0.2 to 0.45 s). In the second phase (from 0.55 to 0.8 s) the line-averaged density is a bit lower so that the plasma transits into a stable detached state. The magnetic configuration is the standard configuration (rotational transform $\iota_a = 5/9$), but with an enhanced plasma radius of 13.6 cm due to the appropriate control coil currents. The neutral beam

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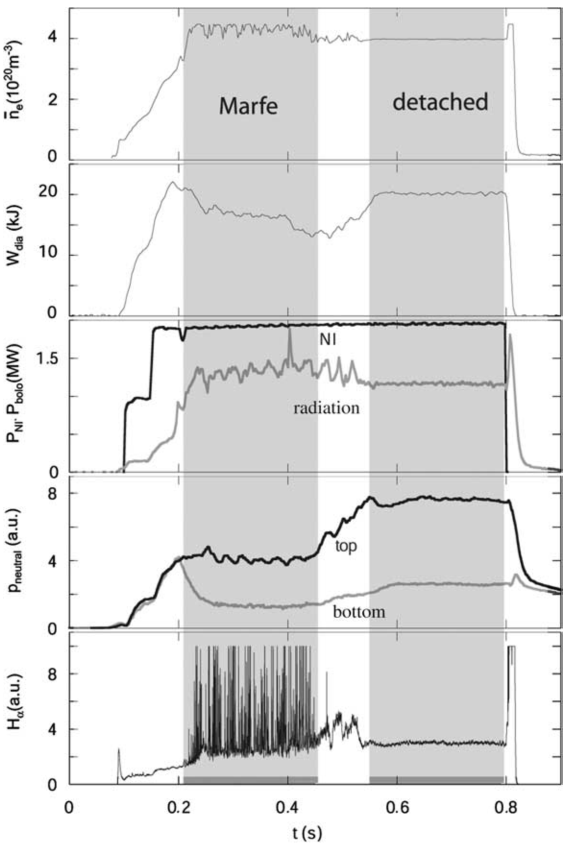

Fig. 1. Signal traces of the Wendelstein-7AS discharge #54470: line-averaged density from bremsstrahlung (n_e), energy content (W_{dia}), neutral beam (P_{NI}) and total radiated power (P_{bolo}), sub-divertor neutral pressures ($p_{neutral}$) and H_α-signal from midplane. The density is ramped-up to the density limit which is characterized by the Marfe. Afterwards the density is slightly reduced so that the plasma transits into the detached state.

power is 2MW (P_{NI}). In the first phase the confinement is degraded as evident by the drop in the diamagnetic energy (W_{dia}). The midplane H_α emission strongly oscillates which is also reflected in the total radiated power.

The sub-divertor neutral pressure in the lower divertor drops. In the second phase the sub-divertor neutral pressure from the lower divertor recovers but now the pressure on top increases. This is a typical feature of the detached plasma in W7-AS which is connected with strong volume recombination between the strike lines on top [7]. Since the direction of the asymmetry depends on the toroidal magnetic field we consider here only the standard case for W7-AS with a negative direction of the magnetic field. The density at the separatrix is about $4\times10^{19}\,\mathrm{m}^{-3}$ (midplane) and in the divertor $0.5\times10^{19}\,\mathrm{m}^{-3}$ [3].

The radiation in the plasma edge was investigated by a set of several CCD cameras. Fig. 6 shows the arrangement of the camera for the observation of the upper divertor. An equivalent camera was used for viewing the lower divertor. A picture of the bottom divertor is shown in Fig. 2. Both cameras were operated with different interference filters to sample the emission of hydrogen and the impurity ions. Since the lines-of-sight run through a large part of the plasma cross-section (cf. Fig. 6) the radiation from the plasma edge was also detected. In the following sections we study the distribution of the plasma radiation for the two characteristic discharge phases.

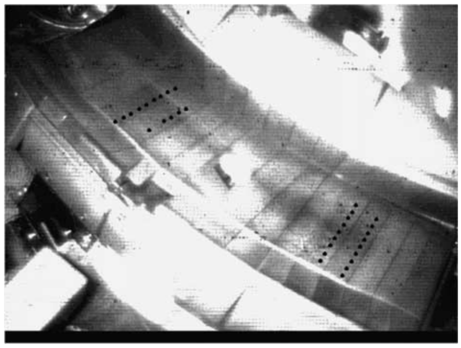

Fig. 2. Picture of the divertor module at bottom taken by a vertical viewing CCD camera. Target tiles 1 and 17 are respectively on the upper left and lower right corner of the image.

3. Plasma radiation in the detached phase

The detached plasma is characterized by a drop of the ion fluxes to the target plates. Since in some regions this drop is not prominent (the plasma stays attached) we have only a partial detachment.

Fig. 3 shows pictures of the divertor plasma at bottom taken with an H_α and a CIII (λ = 465 nm) interference filter. Data is from discharge #56244 at t = 0.45 s. The H_α picture shows the typical strike line pattern (two lines called B and D after [8]). In the CIII picture the corresponding strike lines are also visible. However, the most intense part of the radiation does not originate from the plasma target interaction but from the inboard SOL. The strike lines are only weakly pronounced. The radiation belt is absent or at least weak in the H_α emission. The stripe in the lower left corner of the CIII picture is an extension of the emission from the upper divertor module. Since the total radiative losses are mainly due to the carbon ions CIII and CIV we conclude that the main radiation in the detached state comes no longer from the divertor region but from the inboard edge plasma in the SOL.

Detailed numerical studies on detachment physics have been performed using the EMC3-EIRENE code