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Observations of macroscopic oscillations of the detachment front for injection of H_2, He, and Ne into the simulated baffled divertor

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Abstract

Oscillations of the position of the detachment front have been observed in a linear machine with a simulated baffled divertor with a He plasma for various species of injection gas, i.e., helium, neon, and hydrogen. The oscillation, with a back-and-forth motion, of the detachment front along field lines, accompanies a significant oscillation of the neutral gas pressure in the divertor region. This is due to the fact that plasma plugging depends on the position of the detachment front. The amplitude and period of the oscillation of the gas pressure are largest for neon and smallest for hydrogen, which can be closely related to the plasma pressure at the entrance of the divertor region for the particular gas species.

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1. Introduction

One attractive way to mitigate the heat load focused on the divertor plate in magnetic fusion devices is to dissipate the heat energy on neutral particles using the so-called 'gas-target divertor' method [1]. The plasma-gas interaction enhances plasma momentum loss along the field lines, and finally results in plasma detachment from the divertor plate. A number of studies on linear plasma devices concerning plasma detachment have been performed [2–5]. There is a potential issue that the gas-target divertor method may have negative effects on the high-confinement modes (H-modes) of core tokamak plasmas. Neutral particles leaking from the gas-target region (or divertor region) into the main chamber weaken the radial pressure gradient at the edge of the core plasma [6]. Reduction of the neutral leakage is an important subject for simultaneously achieving both plasma detachment and H-modes. In order to reduce neutral leakage, baffle plates have been located between the divertor plate and the main chamber [7]. In this configuration, denoted herein as a baffled/closed divertor, the neutral leakage through the opening of the baffle is reduced by friction due to ion-neutral collisions. The friction effectively decreases the gas conductance of the opening, which is the so-called 'plasma plugging' effect [2,3]. This effect depends on the upstream plasma pressure at the opening of the baffle. Therefore, the position of the detachment front, z_f, is critical to the plugging, since if z_f is outside the divertor region, the plasma

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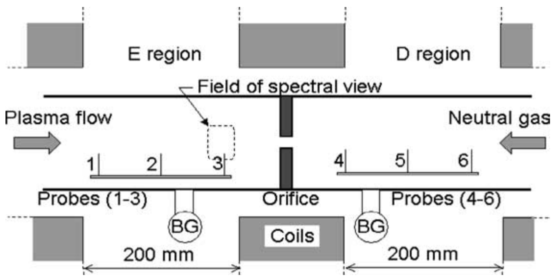

Fig. 1. Schematic diagram of the experimental region and divertor region of the linear machine TPD-II. The plasma is formed to the left of the edge plasma region (labeled 'E') and flows through the baffle orifice to the divertor region (labeled 'D').

pressure at the inlet is lost and along with the friction holding the neutrals back. However, so-called x-point MARFEs make the control of the detachment front more difficult [8].

The stability of the detached plasma was experimentally investigated in a linear machine with a baffle [9]. The baffle plate partitioned the experimental space into two regions: a low-neutral-pressure region and a high-neutral-pressure region, labeled the edge plasma (E) and divertor (D) regions, respectively in Fig. 1. It was observed that when helium gas was injected into the D region, z_f oscillated between the D and E regions (typically, the extent of movement was ~0.5 m, and the period was ~8 s). The back-and-forth motion of z_f was accompanied by a significant oscillation of neutral gas pressures in the E and D regions. In addition to helium gas as ash, gases of other species, for example, hydrogen as a recycling gas and neon as a cooling gas, would also be contained in the divertor region in fusion devices. Thus, the effect of the gas species on the z_f-oscillation is of great interest. In this article, we report z_f-oscillations for different species of gas, namely, helium, neon, and hydrogen. The amplitude and period of the oscillation of the gas pressure were largest for neon and smallest for hydrogen. The effect of gas species on the oscillation is discussed herein.

2. Experimental apparatus and setup

Fig. 1 shows the main experimental part of the linear machine TPD-II (Test Plasma by Direct current) at the National Institute for Fusion Science [9–11]. A helium plasma is continuously generated by a dc discharge between the LaB_6 cathode and the anode in the plasma source region located on the left hand (E region of Fig. 1) side 1.2 m from the orifice. The He plasma enters the E region first and then the D region. The orifice (15 mm in length and 15 mm in diameter somewhat larger than the plasma diameter) between the D and E regions is the equivalent of divertor opening in magnetic confinement devices. All the results presented in this paper were obtained for the axial magnetic field of 0.2 T and the discharge current of 95 A. The electron plasma density was $10^{19}\,m^{-3}$ and the electron temperature was 6 eV, which was obtained by a Langmuir probe located in the E region at 0.2 m from the orifice under the condition without gas injection into the D region.

One of several neutral gases, helium, neon, or hydrogen was injected to cause plasma detachment 1.4 m from the orifice into the D region. The neutral gas flows against the He plasma through the orifice, and is pumped at the E region (the effective pumping speed was $0.3\,m^3\,s^{-1}$ for helium gas). The neutral gas pressures at the D and E regions, P_D and P_E were measured using baratron gauges (BGs) located in the corresponding regions. In the E and D regions, 6 probes for monitoring ion saturation current were placed as shown in Fig. 1. In order to reduce the influence of the probes on the oscillation, the probes were located at radial distances of 15 ± 2 mm and 10 ± 2 mm in the E and D regions, respectively.

3. Experimental results and discussion

Fig. 2 shows the appearance of the oscillation for each gas. When the gas rate, Q_D is increased as shown in frame (iii), P_D and P_E monotonically increase before their oscillations. The ion saturation current I_4 of the probe 4 in the D region simultaneously decreases, reflecting the detachment front and thus the value of z_f moving toward the E region. The value of P_D is saturated at $t \sim 350$ s for helium injection ($t \sim 410$ s for neon and $t \sim 400$ s for hydrogen). At the same time, the detachment front, z_f, appears to reach the position of the orifice. We observe experimentally when the z_f enters the E region, and it starts to oscillate between the E and D regions. Simultaneously the values of P_D, P_E, $I_{1,4}$ and spectral intensities oscillate. Oscillations are stopped for a sufficiently higher value of Q_D, since z_f remains in the E region; this appears for hydrogen and helium, but does not appear for neon in the present range of Q_D. The amplitudes of oscillations are largest for neon and smallest for hydrogen.

More details of these oscillations can be seen in Fig. 3, which shows an enlarged part of the beginning of the oscillation depicted in Fig. 2. As can be seen from Fig. 3(ii), there are two parts in each cycle of P_D-oscillations for all gases: the slow rise and the rapid fall. The first part begins after z_f suddenly changes to the D region. The movement of z_f into the D region appears as the rise in I_4 shown in frame (iv). The increase in P_D is a transient; we postulate that P_D increases toward the saturation value, P_{DS} given by $P_{DS} = P_E + Q_D/C_{eff}$, where C_{eff}