Preliminary Measurements of Low Frequency Fluctuations by a Microwave Interferometer System and a Fast Camera in Pilot-PSI Device

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Pilot-PSI is a magnetized linear plasma device designed for investigating the plasma–surface interactions at ITER-relevant parameters. A frequency-multiplied microwave interferometer system was installed on the Pilot-PSI device for preliminary measurements in the divertor-relevant plasma. We report measurements of the electron line integrated density and its fluctuations. The Hα line emission was monitored using a fast visible camera and was compared with the interferometer data. Both diagnostics measured similar fluctuation frequencies. This suggests that the fluctuations of ions and electrons are well coupled in Pilot-PSI, at least in the plasma regime that was investigated.

Keywords: electron line integrated density, density fluctuation, microwave interferometer, Pilot-PSI

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Intermittent convective plasma transport across magnetic field lines is an important research topic in plasma confinement in magnetized fusion devices [1–6]. For example, nonlinear processes related to instabilities are thought to be responsible for the loss of particles and energy to the wall, commonly referred to as blobs [1–6]. Such processes are observed in toroidal devices during plasma detachment [5, 6] and in linear plasma devices simulating such divertor conditions [1–4]. Detailed studies of blobs and density fluctuations have been mainly performed using Langmuir probes that measure the ion saturation current and floating potential [1–9]. At the same time, the electron density and its fluctuations have not been clearly observed. Microwave interferometry systems are used to measure the electron line integrated density and its fluctuations in divertor-relevant plasmas to better understand the blob dynamics and convective plasma transport across magnetic field lines [10–15]. For example, in GAMMA 10, which is the largest tandem mirror machine, we constructed 70-GHz single-channel interferometer systems, a multichannel interferometer system, and one- and two-dimensional phase imaging interferometer systems [10–12].

Pilot-PSI is a magnetized linear plasma device designed for investigating the plasma–surface interactions at ITER-relevant conditions. Pilot-PSI is unique in producing an extremely high flux plasma beam with a low electron temperature. Previously, plasma rotation velocities owing to the $E \times B$ drift were studied using visible spectroscopy [9]. However, data on plasma density fluctuations are still missing. Thus, Pilot-PSI was chosen for the 70-GHz single-channel interferometer system, which was constructed in GAMMA 10 [12]. In this paper, we report for the first time results of the line integrated plasma density and plasma density fluctuations as measured by this interferometry system on Pilot-PSI. The measurements were supplemented by fast visible camera observations of the Hα line emission in 2D.

Detailed descriptions of the Pilot-PSI linear plasma generator can be found elsewhere [16–18]. It consists of a 1-m-long stainless steel vacuum vessel with a 40-cm diameter. The vacuum vessel is placed inside five magnetic fields coils. Plasma is produced by a cascaded arc discharge operating in various gases. An axial magnetic field up to 1.6 T confines the plasma on the axis of the vessel in the form of a 0.5-m-long beam approximately 1–2 cm in diameter (full width at half-maximum). In this study, the arc was operated in hydrogen at a gas flow rate of 3.5 (standard liters per minute) (slm; 1 slm = 4.5×10^{20} particles/s) and a discharge current of 80 to 100 A. The pressure in the vacuum vessel during the arc operation is typically kept at 1–10 Pa. However, to facilitate the plasma detachment, we varied the background pressure between 5.5 Pa and 18.0 Pa by changing the pumping speed. The electron density and

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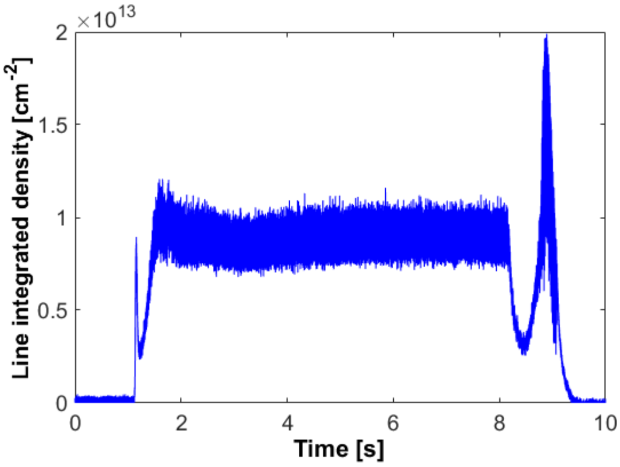

Fig. 1 Line integrated density.

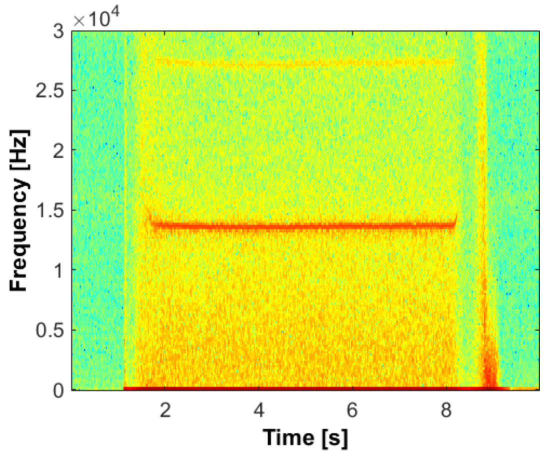

Fig. 2 Spectrogram of the line integrated density.

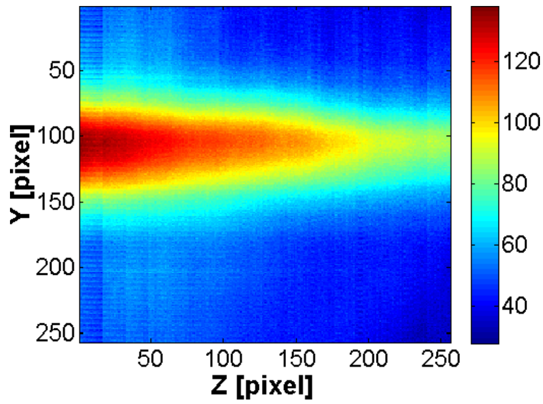

Fig. 3 Fast camera image of the plasma.

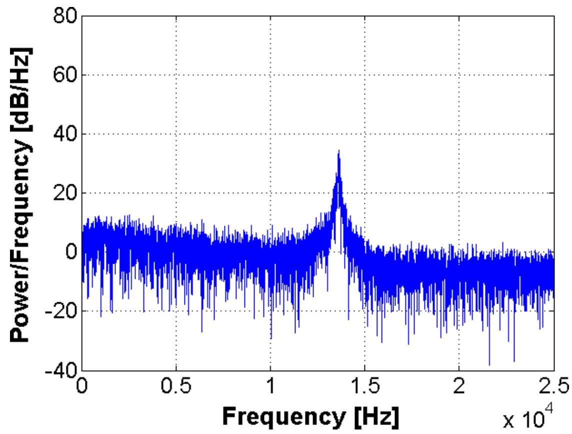

Fig. 4 Normalized FFT spectrum of the intensity.

temperature near the target are less than 1×10^{11} cm^{-3} and 0.1 eV, respectively.

The interferometer system was located either at approximately 290 mm downstream of the source nozzle (z = 290 mm) or at a distance of approximately 30 mm in front of the target surface (z = 550 mm). It is a heterodyne interferometer system equipped with a 17.5-GHz phase-locked dielectric resonator oscillator, a 37.5-MHz temperature-compensated crystal oscillator, as well as frequency multipliers for obtaining the 70-GHz probing beam and reference beam. The interferometer design achieves a frequency-stable interferometer system as a line integrated density monitor compared with a typical nonfrequency-multiplied conventional system. Horn antennas are placed perpendicularly to the plasma beam. The cutoff plasma density of the system is 6×10^{13} cm^{-3}. The spatial resolution of the interferometer system is approximately 3 cm. The phase detection signals were recorded at a sampling rate of 1 MSa/s using an oscilloscope (Tektronix, DPO4034).

Molecular-activated recombination (MAR) and ion electron recombination are efficient production channels for excited neutrals [9]. The Hα emission fluctuation could depend on both the electron density and hydrogen ion fluctuations. To investigate this, a fast visible camera equipped with an Hα band pass filter was used. The Phantom V12.1 (55009 fps, 256×256 pixels, and 12 bit) was located at the same observation port as the interferometer system.

Hydrogen plasma with a magnetic field of 0.8 T, discharge current of 80 A, and plasma duration of 7 s was used. Figure 1 shows the electron line density measured using the interferometer system. The line integrated density is approximately 8.8×10^{12} cm^{-2}. The average electron density is approximately 4.4×10^{12} cm^{-3}. FFT analysis (spectrogram) of the electron line integrated density shows strong low-frequency fluctuation of approximately 13.7 kHz and second harmonics (Fig. 2). In Figs. 3 and 4, we show the fast-camera image at t = 4.0 s and the normalized FFT power spectrum of the intensity at the center of the plasma axis, respectively. The same low-frequency fluctuation was also observed using the fast camera. Fourier analysis of the fast-camera images suggests that the observed fluctuation is related to the plasma rotation. A negative phase angle of approximately 13.7 kHz is observed in the upper half of the images, and a positive phase angle is observed in the lower half of the images. However, it is difficult to obtain the mode number from the camera images. In this plasma conditions, the Hα emission fluctuations depend on both the electron density and hydrogen ion fluctuations.

We have found that the two independent diagnostics measure the same low-frequency fluctuation in Pilot-PSI. This could suggest that the fluctuations of ions and electrons are well coupled in Pilot-PSI, at least in the plasma regime that was investigated. We will continue the study for detailed analysis of electron density fluctuation.

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