Wendelstein 7-X ultrashort electron cyclotron resonance heating discharge for wall conditioning

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Introduction

Wall conditioning decreases the content of light and heavy impurities adsorbed at the inner wall of the device. After wall conditioning, better plasma parameters and longer shots with better density control and higher steady-state temperatures [1] are normally achieved.

Baking, glow discharge conditioning (GDC), electron cyclotron wall conditioning (ECWC), and boronization are used in Wendelstein 7-X stellarator (W7-X) [1, 2, 3]. This report presents the results of research on ultrashort Electron Cyclotron Resonance Heating (ECRH) pulses in hydrogen atmosphere aimed for wall conditioning carried out in the frame of the experimental campaign OP2.1 at W7-X. In addition to the previous works [4, 5], a consecutive series of ultrashort ECRH pulses was launched and analyzed. The studies had been made aimed at shortening the plasma decay stage and thereby increasing the generation rate of atomic hydrogen.

Experimental setup and diagnostics

The experimental research on consecutive ultrashort pulse ECRH discharges was carried out on the W7-X [6], the optimized superconducting stellarator device that can provide steady-state plasma operation to explore the reactor relevance of this variant of the stellarator concept. The ultrashort pulse ECRH discharges were investigated using time slots between the regular ECRH discharges of the W7-X.

The experiments were carried out in a hydrogen atmosphere. The magnetic field was 2.52 T with a high mirror configuration (KKM000+2520). The plasma was created by X2-ECRH discharge at the frequency 140 GHz [7]. The plasma density was measured by the Integral

Electron Density Dispersion Interferometer (IEDDI) [8]. The emission intensity of spectral lines was recorded by HEXOS (High Efficiency XUV Overview Spectrometer) [9].

Experimental Results

The regular ECRH discharge and the ultrashort pulse ECRH discharge sequence are shown in Fig 1.

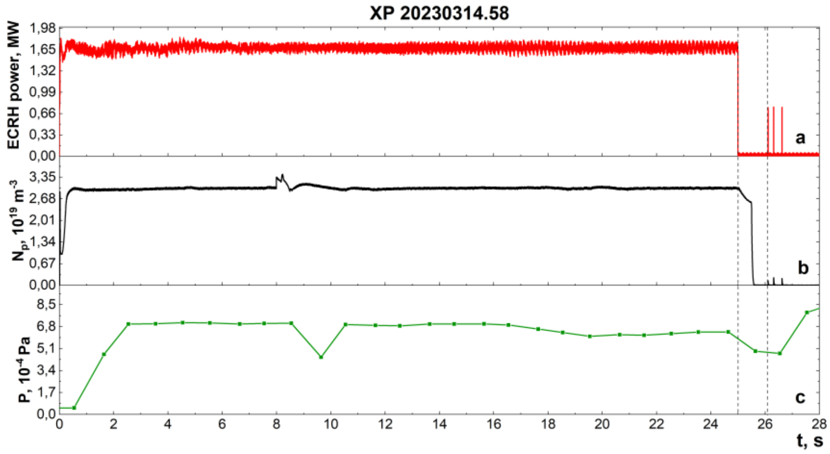

Fig. 1 – Time dependence of total ECRH power (a), plasma density (b), and average neutral pressure (ADB -average) (c) for the pulse XP 20230314.58 (in H_2).

The duration of regular ECRH discharge is 25 s with a total X2-ECRH power of about 1.75 MW, which produced a plasma density about $3 \cdot 10^{-19}$ m^{-3}. In the time slot 26.1 – 26.6 s after the regular discharge, there were 3 ultrashort pulses with a total ECRH power 0.75 MW. The produced plasma is much less dense with a maximum value about $0.235 \cdot 10^{19}$ m^{-3}. The gas H_2 injection was not done during these 3 ultrashort pulses.

In Fig. 2, 3 (a, b, c) a consecutive series of ultrashort pulse ECRH are shown. In the vacuum chamber H_2 pressure was 0.64 Pa and 1.13 Pa for pulses XP 20230314.58 and XP 20230314.62 respectively. The ECRH power for these two discharges is nearly 0.73 MW, and the maximum density is about $0.235 \cdot 10^{19}$ m^{-3} accordingly. Also, the time dependence of line H I (121.5670 nm, Lyman alpha) intensity registered by HEXOS is shown. In Fig. 2, 3 you can see three and four ultrashort pulses. The duration of each pulse is ≈ 7 ms. The duration between pulses for discharge XP 20230314.58 is $\Delta t_1 \approx 100$ ms and $\Delta t_2 \approx 300$ ms. The duration between each pulse for discharge XP 20230314.62 remains constant with a value 100 ms ($\Delta t_1 = \Delta t_2 = \Delta t_3$). The maximum plasma density occurs during the second consecutive ultrashort pulse following regular ECRH discharge XP 20230314.58 and XP 20230314.62. After the second ultrashort pulse in the series, a slight decrease in plasma density is observed with each subsequent pulse.

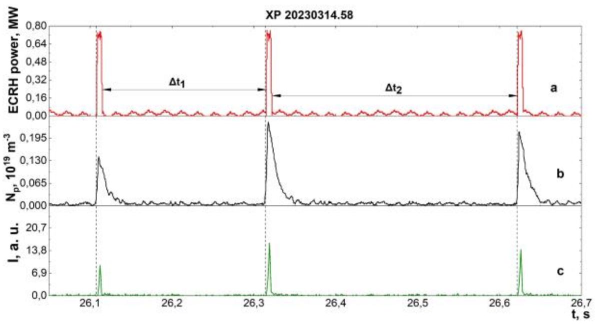

Fig. 2 – Time dependence of total ECRH power (a), plasma density (b), and line H I (121.5670 nm, Lyman alpha) intensity for pulse XP 20230314.58 H_2 P = 6.4×10^{-4} Pa, $\Delta t_1\approx200$ ms, $\Delta t_2\approx300$ ms)

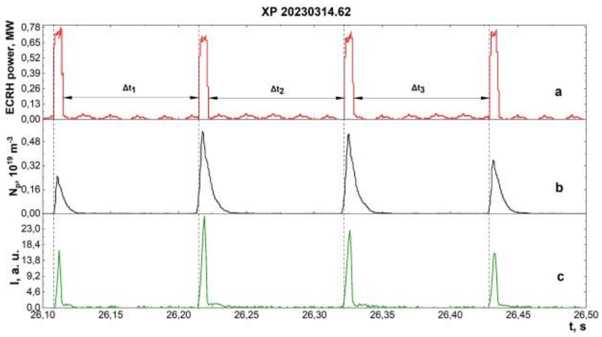

Fig. 3 – Time dependence of total ECRH power (a), plasma density (b), and line H I (121.5670 nm, Lyman alpha) intensity for discharge XP 20230314.62 (H_2 P = 1.1×10^{-3} Pa, $\Delta t_1\approx\Delta t_2\approx\Delta t_3\approx100$ ms)

In Fig. 4 you can see maximum density dependence for ultrashort ECRH on pressure. It can be noticed a growth of maximum density with growing pressure.

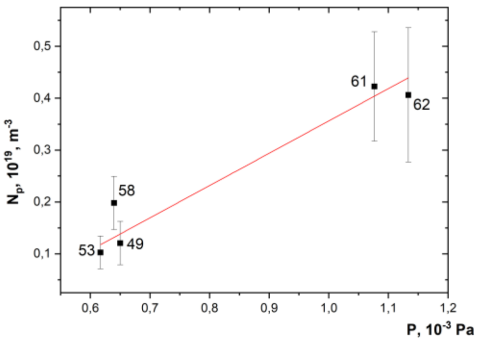

Fig. 4 - Dependence of maximum density ultrashort ECRH on pressure. XP 20230314.(Numbers in the figure, discharge numbers).

The intensity of lines atom HI (121.5670 nm) and ions CII (90.4080 nm), and CIII (117.6370 nm) registered by HEXOS is shown in Fig. 5. Also, with dashed lines the start and the end of ECRH injection are shown. The appearance of the carbon lines is observed with a time delay relative to the appearance of the hydrogen line. The intensity of lines for ions with a high ionization stage is not registered for ultrashort pulses. In Fig. 6 calculated relative population levels of excited hydrogen atoms are shown.

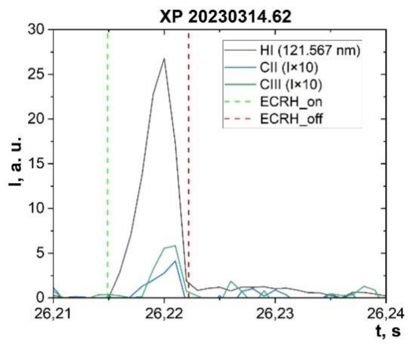

Fig. 5 – Dependences of lines intensity on time for pulse XP 20230314.62 (H_2 P = 1.1×10^{-3} Pa)

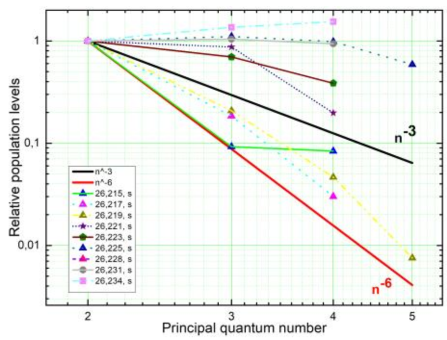

Fig. 6 – Calculated relative population levels of excited hydrogen atoms at different ultrashort pulse times

The dependences of the relative population of the excited atoms on the main quantum number at different phases of the plasma decay (XP 20230314.62) are calculated using Einstein coefficients. The black line n^{-3} represents the slope of the function describing a collision-radiation process, while the red line n^{-6} corresponds to the slope of the function describing the dissociation of molecular hydrogen by electron impact [10]. After shutting off the ECRH power supply, the dissociation and recombination processes are observed.

Conclusion

The experiments have shown the realization of the series of consecutive ultrashort ECRH pulses at W7-X in a hydrogen atmosphere. This scenario is aimed at providing atomic hydrogen generation for wall conditioning. A series of the 0.73 MW ECRH pulses of 7 ms duration creates the bursts of plasma with a maximum density of about $0.23 \cdot 10^{19}$ m^{-3}. Pulses are stable in series. The variation of times between ultrashort ECRH impulses does not significantly change the plasma parameters. The plasma decay time is shorter than the particle confinement time that indicates intense recombination which contributes to atomic hydrogen generation. In the further experiments in OP2.2/2.3, to see the impact on wall conditions (removing impurities from the surface), a durable series of such pulses needs to be carried out.

Acknowledgement

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