Ultrashort pulse series of electron cyclotron resonance heating for wall conditioning at Wendelstein 7-X

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One of the effective methods of plasma discharge wall conditioning in fusion devices is hydrogen wall conditioning [1], the principle of which is to produce atomic hydrogen, which, in turn, chemically interacts with impurities at the wall surfaces. The reaction is aimed to produce light volatile substances that can be removed by a pumping system.

A scenario for wall conditioning Wendelstein 7-X (W7-X) stellarator using a pulsed ECRH discharge was proposed [2], the feasibility of which was demonstrated during the OP1.2b experimental campaign, where a chain of electron cyclotron heating ultrashort pulses was investigated, and also confirmed by numerical calculations [3]. Within OP2.1 experimental campaign, a series of such sequential ultrashort ECRH pulses [4] was tried at W7-X.

In further experiments in OP2.2 described here, a longer series of such pulses had been launched mainly to study longer programs. This report presents the results of these experimental studies and the results of numerical simulations.

Experimental Results

During this series of experiments, the plasma was produced using an X2-ECRH discharge at a frequency of 140 GHz [5]. The working gas is hydrogen, and the magnetic field at the magnetic axis is 2.5 T. The diagnostic equipment of the W7-X stellarator is described at [6, 7].

The time dependences of total ECRH power, evaluated plasma density, and intensity of several spectral lines are shown in Fig. 1 of two of the programs of the above-mentioned series. In the program 20241121.50, the high power 0.1 s long ECRH pulse goes first, and a chain of ultrashort pulses with duration of 3 ms and a period of 0.1 s goes after. In Fig. 1 (left) we see that the plasma decay time is longer than the decay time from a conventional single pulse [2, 4]. The short pulses that follow the initial pulse possibly prolong the plasma decay time. However, the plasma density evolution does not show any response to any of them.

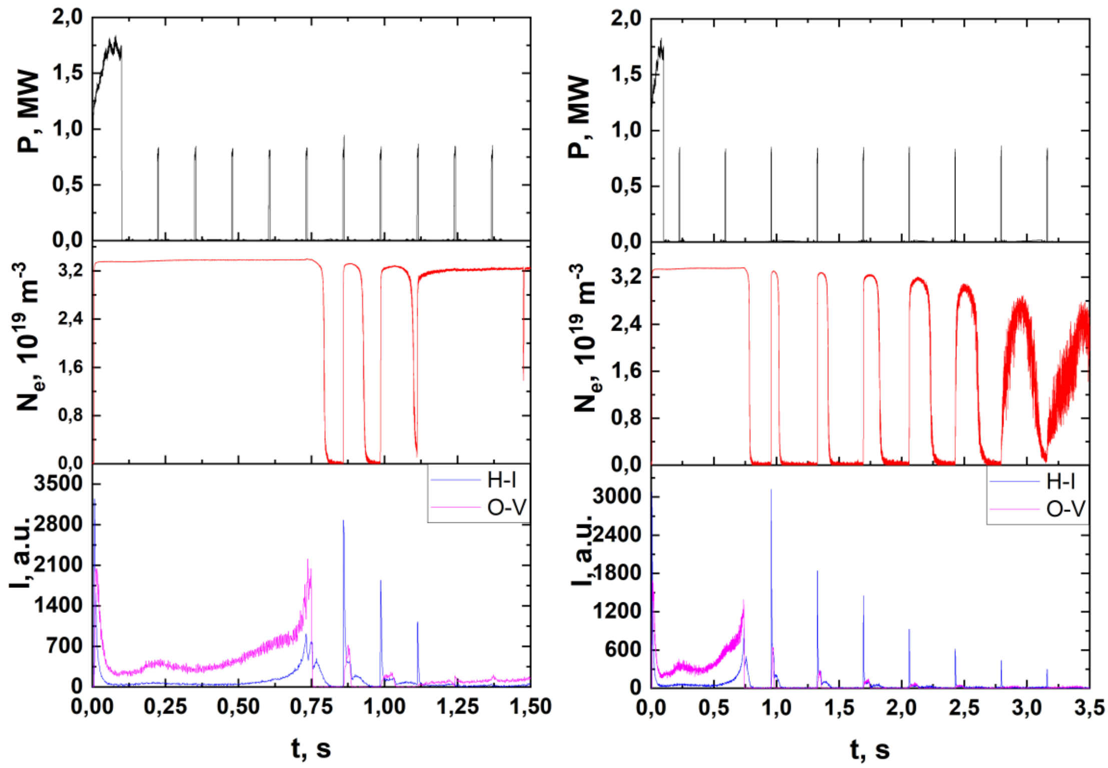

Fig. 1. Time evolution of total ECRH power, evaluated plasma density (N_e=∫ndl/L, where L is the length of the averaging line) and intensities of spectral lines HI (121.567 nm), OV (62.973 nm) in the programs 20241121.50 (left) and 20241121.54 (right)

The optical lines HI and OV are shown in Fig. 1. They have a peak at the beginning of the initial pulse and significantly decrease after. However, the line OV does not drop down after the initial pulse end, and at t=0.4 s even starts to grow. Later, at t=0.6, HI line shows growing. Then, at approximately 0.75 s, we observe a collapse. In the time interval 0.2<t<0.75 s we also do not see the influence of the pulses (see Fig. 1) on the intensity optical lines. After the collapse, the OV line instantly fades, and the hydrogen line is observed until the plasma density decay. This is most likely a result of recombination. Such a behavior of the optical lines can be explained by the presence of some energetic electrons created by the ECRH, which support this process.

And then the process begins without the influence of the initial pulse.

When the next pulse after the collapse passes, the intensity of the hydrogen line HI is approximately the same as at the beginning of the initial pulse. Then the plasma is produced and decays in a normal way. During the discharge development, the OV line rises up with some delay relative to the hydrogen line. Then the OV stops, which can be explained by the temperature decrease, and the recombination emission of HI appears in a few milliseconds.

At the next pulse, the peak of the hydrogen intensity has a smaller amplitude. The intensity of the OV and the recombination intensity also decrease. Nevertheless, the plasma density peak remains almost unchanged, and the plasma decay takes longer. At each subsequent pulse, the hydrogen peak and OV amplitude gradually decrease, and the plasma density the same maximum.

There is a slow varying part in OV luminosity that gradually grows up to the program end. Its amplitude is smaller than at the first part of the program. It could be suggested that the group of accelerated electrons is formed again after the collapse, but is less populated because of the smaller average ECRH power of the ultrashort pulses.

Figure 1 (right) shows one of the next programs of the series, program 20241121.54. This program differs from program 20241121.50 in that the pulses are followed less frequently. The processes in the program 20241121.54 are less fast, but the trend persists and, in general, a similar picture, as in 20241121.50, is observed.

Numerical simulation results using the updated theoretical model [3, 8] are presented in Fig. 2. The following parameters of numerical calculations are chosen: the major radius of the torus is R=5.5·m, the characteristic radius of power deposition is r_{pl}=0.15 m, the radius of the metallic wall is a=0.6 m, the initial plasma density is $n_{e0}=1\cdot10^{14}$ m^{-3}, the initial density of the neutral gas is $n_0=2\cdot10^{18}$ m^{-3}. Fig. 2 shows the time evolution of the electron density for a program with a first high-power ECRH pulse of 0.1 s duration and a chain of ultrashort pulses of 3 ms duration and 0.1 s period.

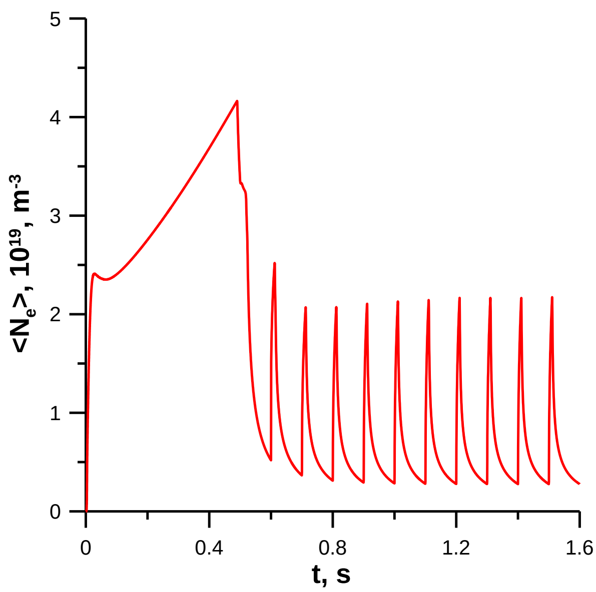

Fig. 2. Time evolution of electron density for program with ECRH pulses

The numerical modeling performed is somewhat different from the results obtained during the experiments. In the numerical experiments, we assumed that the gas was hydrogen at each moment. For this reason, the pulses quickly reach a quasi-stationary state, and the plasma decays all the time (Fig. 2).

The difference between the numerical modeling and the experiment arises because the modeling does not take into account the influx of impurities and changes in the composition of the working gas, as well as the formation of a small beam of hot electrons. These factors are decisive in the experiments.

End Note

The series of ultrashort ECRH pulses in a hydrogen atmosphere creates cold hydrogen plasma suitable for wall conditioning. The distinctive feature of this series is that the programs have non-stationary plasma evolution on a time scale of seconds. Among the phenomena which are hard to explain in the frame of enabled diagnostics is the complexity of OV optical line behavior, the decrease of HI peaks of ultrashort pulses with pulse number, etc. The answers to these questions should be found in further studies.

Acknowledgement

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 – EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

The financial support of the National Research Foundation of Ukraine (grant 2023.03/0101) is acknowledged. This study is financially supported in part by the Swedish Foundation for Strategic Research (grant UKR24-0015) and by Ministry of Education and Science of Ukraine (grant PH/56-2024).

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