Study of plasma start-up assisted by second harmonic electron cyclotron heating: from experiment to modeling

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One of the specific purposes and tasks of the Electron Cyclotron Resonance Heating (ECRH) system on both tokamaks and stellarators is to provide a reliable plasma start-up. For the two upcoming biggest experiments in the world, ITER and W7-X, large ECRH systems are foreseen: 24 MW on ITER and 10 MW on W7-X.

Contrary to the start-up in a tokamak where an induced loop voltage generates a plasma current, a reliable plasma start-up in a stellarator uses ECRH only (or NBI). Indeed, since the rotational transform (ι) and thus the confining magnetic field already exist in vacuum, a loop voltage can be omitted. Therefore, the plasma start-up requires an external heating source in a stellarator. Moreover, pre-ionization and assisted start-up with ECRH will be necessary in ITER due to the low electric field available ($\leq 0.3\ V/m$).

Although both 1st harmonic ordinary mode (O1) and 2nd harmonic extra-ordinary mode (X2) have been successfully used to assist pre-ionization and breakdown in many devices, a complete theoretical model is still missing to explain the success of this method in particular in X2-mode on stellarators like WEGA. Moreover, some experimental observations are not completely understood, such as what occurs during the delay time between the turn-on of ECRH power and first signals of density or light measurements. This delay time can last up to several dozens of milliseconds. Since during this free period the ECRH power has to be absorbed by in-vessel components, it is of prime importance to know what governs the dependence of this delay time on ECRH power characteristics, gas pressure, and rotational transform. Recent dedicated start-up experiments have been performed on WEGA, using a 28 GHz ECRH system in X2-mode. This machine has the interesting capability to be run also as a tokamak allowing comparative experiments between stellarator ($\iota > 0$) and tokamak ($\iota = 0$) configurations. Different scans in power, pressure, and rotational transform show clearly that the start-up is a two step process. A first step after the turn-on of the ECRH power during no electron density, no ECE and visible light emission and no radiated power are measured. Its duration depends strongly on the level of injected power. The second step corresponds to the gas ionization and plasma expansion phase, with a velocity of density build-up and filling-up of the vessel volume depending mainly on pressure, gas and rotational transform. Moreover, results from this experimental parametric study are useful for the modeling of the start-up assisted by the second harmonic electron cyclotron heating. The aim of this work is to establish predictive scenarios for both ITER and W7-X operation.