Contribution ID: **224**

Type: **Poster**

ECRH and mode conversion in overdense W7-X plasmas

Wednesday, 24 October 2018 14:00 (20 minutes)

Electron Cyclotron Resonance Heating (ECRH) is the main plasma heating mechanism in Wendelstein 7-X (W7-X) Stellarator. It is provided by 10 gyrotrons at 140 GHz (corresponding to the second harmonic cyclotron resonance at 2.5 T) with the power of 1 MW each. The X- and the O-modes were successfully used in a wide range of operation scenarios: X-mode for low and moderate densities (up to the cutoff at $1.2 \cdot 10^{20} m^{-3}$), and O2-mode for higher densities (up to ~$2 \cdot 10^{20} m^{-3}$).

Possible operation at yet higher densities would involve double mode-conversion from O- to slow X- and to Bernstein-mode, i.e. an OXB-scenario. The physics of O-X conversion is outside of applicability of the routinely used geometrical optics approximation (WKB-theory) and should be considered within a full-wave approach.

In this work, the wave physics of O-X conversion in overdense W7-X plasma is investigated. The results are also applicable to the inverse problem of electron Bernstein emission (EBE) diagnostics.

The work discusses: (a) Possibilities for the realization of this mode conversion scenario within the capabilities of the existing ECRH system in W7-X; (b) Development of the “optimal” O- to X- conversion scenario within the constraints set by the 3D plasma equilibrium. A feasible heating scenario with >85% efficiency is identified. (c) The effect of turbulence on the conversion efficiency is assessed.

For this study, a new 3D, cold plasma full-wave code has been developed. The code utilizes the Finite Difference Time Domain (FDTD) technique. The computational domain is “minimized” around the WKB-trajectory of the reference ray, and is matched to the surrounding plasma by using the so-called “convolutional perfectly matched layers (CPML) boundary condition”. The background magnetic field is recovered from the pre-computed 3D equilibrium data. The code takes advantage of massive parallel computations with Graphics Processing Units (GPUs), which allows for up to 100 times faster calculations than on a single-CPU. This feature allows for efficient parametric optimization studies over a broad range of possible experimental conditions.

Country or International Organization

Germany

Paper Number

TH/P4-6

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Session Classification: P4 Posters