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Modelling of ECRH/ECCD at different power launch geometry in T-15MD tokamak

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The first experiment on T-15MD tokamak at the National Research Center Kurchatov Institute is planned for the end of 2020. T-15MD is the tokamak of D-shaped plasma with aspect ratio ˜2.2, toroidal magnetic field B_T to 2 T in the center of the vacuum chamber, with a plasma major radius of 1.48 m, with a minor radius of 0.67 m, elongation, k, to 1.8 and a triangularity, δ, to 0.4 [1]. Electron-cyclotron heating and current drive (ECRH/ECCD) using eight gyrotrons with output power 1 MW per gyrotron is considered as one of the methods of heating and noninductive current drive in the T-15MD. The peculiarities of the ECRH/ECCD system of the T-15MD tokamak in different modes of operation are analyzed in frames of this paper.
The geometry of EC wave launch into the plasma of the T-15MD tokamak is shown in Figure 1. During the start-up phase, one gyrotron with output power 1 MW will be used to provide the breakdown conditions. Power input will be performed using focusing mirrors through the equatorial port (Figure 1). Steerable mirrors will be installed in order to change the launch angle in both the poloidal and toroidal directions. At the first stage of operation the poloidal angle of microwave power input will vary in the range of $-5^o ... +30^o$, toroidal angle in the range of $-20^o ... +20^o$.
In order to select the frequencies of gyrotrons including the frequency of the first one which provides the microwave breakdown, an analysis of the operating area of the T-15MD tokamak was carried out. It is shown that for EC waves with the frequency in the vicinity of 80 GHz at the second harmonic of the electron-cyclotron frequency, the EC resonance zone is located inside the vacuum chamber of the device in regimes with the toroidal magnetic field, B_T, in range of 0.8 T to 2.2 T. Thus, the EC wave frequency f = 82.6 GHz is selected for the breakdown assistance for the first experiments.
Modelling of the microwave heating and current drive using an extraordinary electron-cyclotron wave with f = 82.6 GHz on the second harmonic of the EC frequency is performed using the ASTRA [2] and OGRAY [3] codes. Simulations are carried out for the different T-15MD conditions, including experiments with high Shafranov's shift. The configurations with various plasma shapes are considered (circular plasma, D-shaped cross-section with different values of k and δ). To simulate microwave-plasma interaction in H-mode the density and temperature profiles given in [4] are used.
On-axis power distribution (ρ<0.1) of EC wave with f = 82.6 GHz can be provided in the regimes with different Shafranov's shift values (from ˜ $6-10$ cm to ˜ 20 cm) by the toroidal magnetic field variation in the range of B_T ˜ $1.5-1.7$ T. The expected current drive efficiency up to $0.4 \cdot 10^{19}$ A/W/m^2 is predicted at the toroidal launch angle of 20^o, which is slightly higher than the values experimentally obtained on the second ECR harmonic at various machines [5]. At the magnetic field close to the value of 2 T, the power distribution becomes strongly off-axis and located at ρ˜0.75. In order to provide an on-axis ECRH/ECCD at B_T ˜ 2 T, gyrotrons with the frequency in the $102-110$ GHz range are considered.
Modelling shows that for the estimated microwave beam launched in the equatorial plane along the plasma major radius there is a complete single-pass absorption up to the input power value of ˜2.5 MW in the regime with the plasma density $n_e(0)$˜$2.7 \cdot 10^{19}$ m^{-3} (the beam half-width of D_w = 2.4 cm by e^{-1} level and the wave front curvature of R_w=70 cm at the input to the tokamak). A further power increase can lead to an increase in the role of non-linear effects, manifested in a decrease of the fraction of the absorbed power. In a real experiment (eight independent beams from eight independent launchers) the absorption area will be wider. However, possible influence of non-linear effects should be taken into account and estimated especially in the cases of the high ECRH power value. The localization of the EC power absorption can be additionally expanded, for example, by a small (˜ $1-2^o$) variation of the poloidal angle of each of the beams used. Note, that discussed density value corresponds to the 80% of the cut-off density for the EC wave of extraordinary polarization on the second harmonic of the ECR with f=82.6 GHz.
Figure 2 shows the calculated power depositions for a single 1 MW beam launched from the equatorial (Figure 2, a) and upper (Figure 2, b) ports. It is seen the EC power deposition moves from on-axis position to off-axis with ρ ˜ 0.6 for the equatorial power launch and the range of the poloidal angles mentioned above. Beam launch through the upper port will allow to extend the range of a heating positions to ρ ˜ 0.8 that can be important for the H-mode.

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Figure 1. Proposed geometry of the microwave power launch to the plasma of T-15MD tokamak.

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Figure 2. Heating power profiles calculated by the OGRAY code for the equatorial (a) and upper (b) launch geometries for different values of a poloidal launch angles, ϕ_p. Negative ϕ_p values correspond to the direction down. The value of the central electron density $n_e(0)$ is given in m^{-3}.

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