Lower hybrid current drive modeling for spherical tokamak Globus-M

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It is well known that the lower hybrid (LH) wave parallel refractive index should satisfy the following accessibility criterion $|N_\parallel| > N_{\parallel cr} = \omega_{pe}/\omega_{Be} + \sqrt{1 + (\omega_{pe}/\omega_{Be})^2}$ to contribute to the LHCD in the inner plasma region where the value of ω_{pe}/ω_{Be} is calculated in this formula. The LH (slow) waves with $|N_\parallel| < N_{\parallel cr}$ cannot reach the inner plasma region as they are converted into the fast waves and reflected back. For spherical tokamaks (STs) it is typical to operate at comparatively low magnetic field and rather high plasma density, when

Figure 1: LH antenna.

$\omega_{pe}/\omega_{Be} \gg 1$ in the region of interest and, as a result, $N_{\parallel cr} \gg 1$. The direct excitation of the waves with $N_{\parallel cr} \gg 1$ would have a very poor efficiency because of the wide evanescent region for the LH waves at the plasma periphery. Besides, even setting aside the coupling problem, those waves would be absorbed by the electron Landau damping mechanism close to the plasma periphery. To overcome this problem the initial spectrum of LH waves should be slowed down in the poloidal rather than the toroidal direction [1]. This provides an opportunity to use an additional transparency window for the LH waves [2] arising from large values of the non-diagonal component g of the dielectric tensor and of its gradient typical for the STs. It is shown in [2] that usual local dispersion relation $D_0(\mathbf{N}, \omega, \mathbf{r}) = 0$ is applicable when $N_y \cdot dg/dx \ll 4\varepsilon N_x^2$, otherwise it must be replaced by a more general formula $D_0(\mathbf{N}, \omega, \mathbf{r}) + \delta D = 0$, where δD depends on g and its gradient. As a result of strong poloidal magnetic field inhomogeneity in spherical tokamaks even the waves with comparatively weak poloidal slowing down can penetrate into the dense plasma and be absorbed via the Landau mechanism. This approach was applied for modeling future LHCD experiments in the low aspect ratio tokamak Globus-M ($R = 0.36\,m, a_0 = 0.24\,m, B_0 = 0.4\,T, I_p = 0.25\,MA$, vertical elongation $k = 1.6$, operating frequency 2.45 GHz). The modeling was carried out using the self-consistent antenna coupling code GRILL3D [3] and the Fast Ray Tracing Code (FRTC) [4, 5] modified to include the extended dispersion relation [2] and allowing simulation of the driven current density profile. In present paper modeling results for expecting lower hybrid current drive experiments on spher-
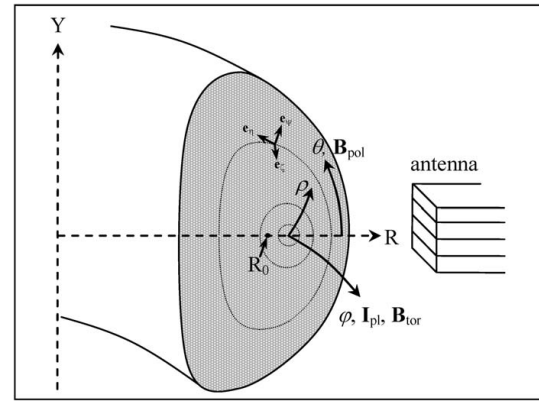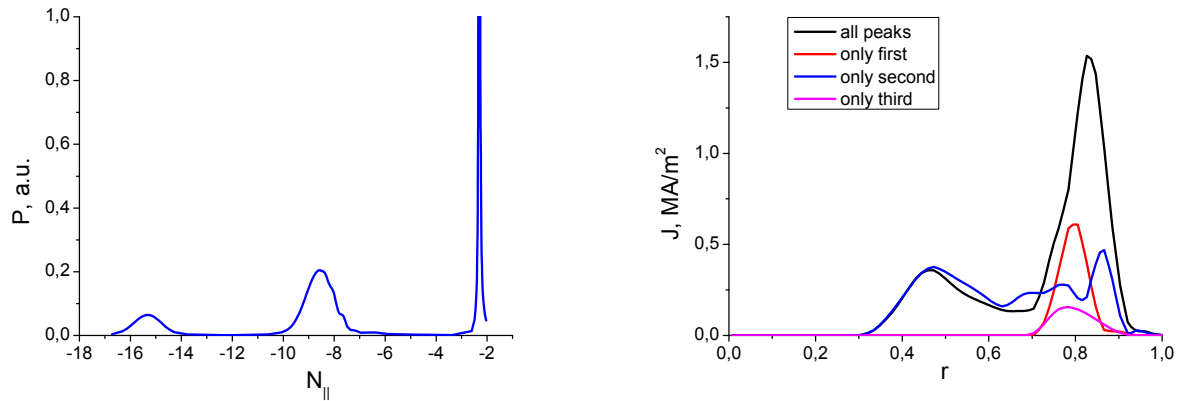
Figure 2: First grill design. $N_\parallel$ spectrum and LH driven current profiles for $B_0 = 0.4\ T, I_p = 0.25\ MA$; $I_{LHCD} \approx 100\ kA$.
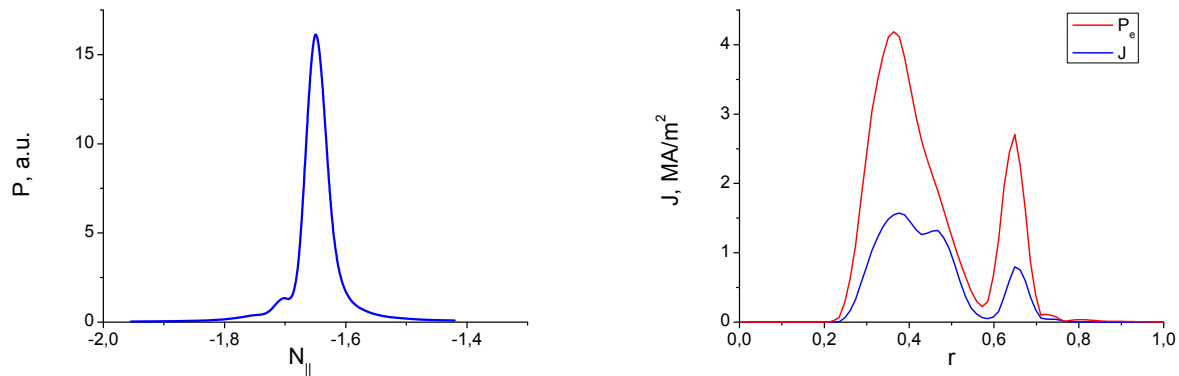
Figure 3: Current grill design. $N_\parallel$ spectrum and LH driven current profiles for $B_0 = 0.4\ T, I_p = 0.25\ MA$; $I_{LHCD} \approx 85\ kA$.

ical tokamak Globus-M are presented for existing tokamak parameters and for planned in the future modernized magnetic configuration with increased magnetic field and plasma current as well. It is shown in the paper that the increase of the toroidal magnetic field, plasma current and temperature are favorable for the lower hybrid current drive efficiency.

The layout of the LH experiment in Globus-M tokamak is shown on Figure 1. First self-consistent modeling of the grill operation was carried out with the GRILL3D code [3] using plane, 1D inhomogeneous plasma model. Several possible grill configurations were considered. The basic one consisted of 12 waveguides with adjoining broad sides, stacked either horizontally (conventional grill) or vertically ('poloidal' grill), so that the waveguide electric field was aligned with the toroidal or the poloidal direction, respectively. Waveguide openings' width was equal to 7.5 *mm*, the septum width was 1 *mm*. Phase shift between adjacent waveguides could

be varied, usually it was either -90° or $+90^o$. No multi-junction scheme was used, since we prefer to have a maximum flexibility in varying waveguide phasing in experiments. In most cases angle between the plasma magnetic field and the toroidal direction was taken equal to 28° that corresponds to the actual value in front of the antenna (we assumed positive toroidal components of both magnetic field and plasma current). Modeling results for typical Globus-M plasma parameters and $N_\parallel$ spectrum produced by this basic grill configuration is shown in Figure 2. In this case the LH driven current is about 100 kA, that is 40% of the total plasma current. Unfortunately, manufacturing of this grill design turned out to be too expensive, therefore another, much cheaper grill design will be used in Globus-M experiments. Namely, the grill will be constructed from the standard waveguides having 20 mm width and 4 mm septum width. The spectrum of this grill consisted of one peak at $N_\parallel \simeq -1.65$ is shown in Figure 3 together with LH driven current profile. Value of LH driven current here is about 85 kA which is less than LH current the in previous case.
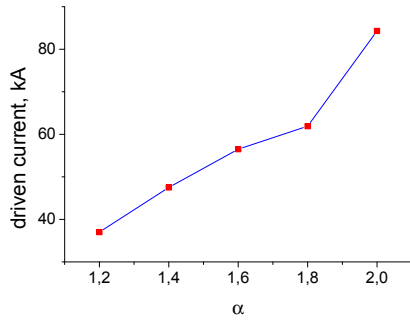
Dependence of LH current on plasma density profile is illustrated by Figure 4, where the amount of driven current is plotted against the power coefficient α used for modeling with one-peak spectrum in the following formula for plasma density: $n_e = (n_0 - n_b) \cdot (1 - \rho^2)^\alpha + n_b$. It is seen from this simulation that narrower plasma density profiles are preferable for LHCD in Globus-M. After Globus-M modernization planned in near future the toroidal magnetic field and plasma current will increase from the present values of $B_0 = 0.4\ T$ up to $B_0 = 1\ T$ and from $I_p = 0.25\ MA$ up to $I_p = 0.5\ MA$, correspondingly. This considerable increase of magnetic field significantly facilitates accessibility conditions for the LH waves at plasma periphery and actually converts Globus-M from spherical tokamak to a conventional one from the viewpoint of propagation of the LH waves. Also it is estimated from transport analysis based on present day experimental electron and ion heat diffusivities and particle diffusion coefficients, that the electron plasma temperature in the modernized Globus-M exceeds 1 keV, which is favorable for the LHCD as well. All these improvements should increase the expected LH driven current in the modernized Globus-M. Results of corresponding modeling are shown in Figure 5, where for one-peak $N_\parallel$ spectrum and poloidal grill orientation it is found that $I_{LHCD} \approx 200\ kA$ and $I_{LHCD} \approx 460\ kA$ for conventional toroidal grill orientation. Modeling shows that larger driven current in the lat-
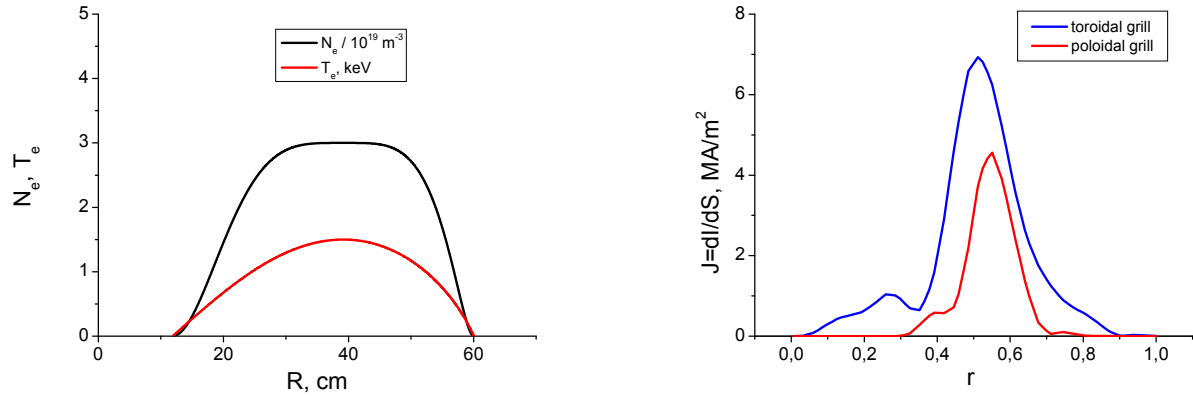

Figure 4: Dependence on α of the LH driven current in Globus-M for one-peak spectrum.

Figure 5: Current grill design. N_e, T_e plasma profiles and LH driven current profiles for modernized Globus-M parameters $B_0 = 1\ T, I_p = 0.5\ MA$. Larger LH current ($I_{LHCD} \approx 460\ kA$) is for conventional 'toroidal' grill orientation, smaller LH current ($I_{LHCD} \approx 200\ kA$) is for 'poloidal' grill orientation.

ter case is due to formation of more extended quasilinea plateau in the electron distribution function compared to the poloidal grill orientation case.

Summary

Simulations predict LH driven current about 100 *kA* for existing Globus-M plasma parameters and poloidal grill orientation. Increased magnetic field, plasma current and temperature in modernized Globus-M will permit to drive LH current about 200 *kA* for poloidal grill orientation and about 460 *kA* for toroidal one. Both grill orientations will be possible in the future experiments. Self-consistent "LHCD + transport" simulations should be performed on the basis of future experimental electron heat conductivity measured during LH pulses.

Acknowledgement

References

[1] E. Z. Gusakov, V. V. Dyachenko, M. A. Irzak et al., PPCF **52**, 075018 (2010)

[2] E. Z. Gusakov, M. A. Irzak and A. D. Piliya, JETP Lett. **65**, 25 (1997)

[3] M. A. Irzak and O. N. Shcherbinin, Nucl. Fusion **35**, 1341–56 (1995)

[4] A. R. Esterkin and A. D. Piliya, Nucl. Fusion **38**, 1501 (1996)

[5] A. D. Piliya and A. N. Saveliev, Preprint JET-R **01**, (1998)