Fullwave antenna modeling of LHCD and ICRF antennas on the WEST tokamak using Petra-M

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This paper reports on the recent progress of radio-frequency (RF) actuator modeling and its application to the lower hybrid (LH) waves and ion cyclotron (IC) RF experiments on the WEST tokamak. We developed an open source finite element analysis platform, Petra-M [1, 2]. Petra-M is based on the MFEM [3], scalable FEM library developed by LLNL. In Petra-M, we combine various open source software to allow for performing the finite element analysis from CAD based parametrized geometry to FEM linear system assembly and a linear system solution in a seamless manner. Petra-M allows for solving the RF wave propagation problem in plasmas in the large (normalized by the wave length) computational domain. Motivation to apply Petra-M on the WEST tokamak includes (1) assessing the interaction between different ICRF antennas and (2) investigating the impact of 3D and background plasma on the LH launcher coupling and direct comparison of computed wave electric field with the DSELF diagnostics [4, 5].

In this initial report, we modeled the IC wave propagation in a 40-degree sector of WEST tokamak plasma and the LH wave excitation by the fully active LH1 launcher. In both modeling, the curved 2nd order finite element mesh for the computation domain is prepared directly using CAD geometry data (Figure 1 and 2), resulting in faithful representation of antenna structures. A series of 2D Petra-M axis-symmetric simulations were performed for both IC and LH waves (not shown here) to estimate the mesh size requirements for the 3D simulations. In the IC case, the entire geometry is meshed with the element size of 2-4cm based on the resolution required to resolve the fast wave. In the LH case, we simulate the wave propagation only in front of the antenna including SOL (3cm), core (3cm), and limiter shadows. The mesh elements are stretched in the toroidal direction, so that we can consider a large enough plasma region in front of the LH antenna, while keeping DoFs low enough.

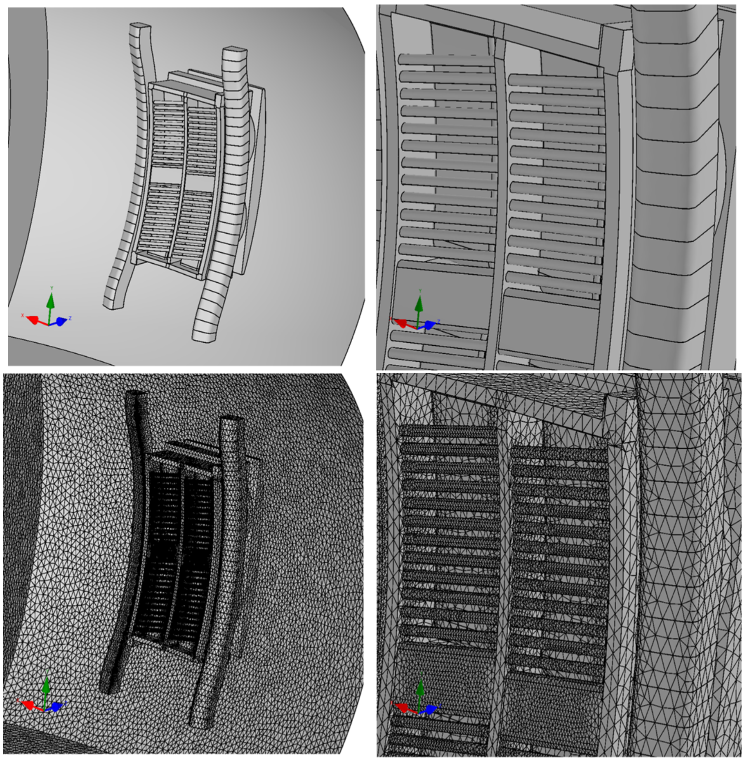

Figure 1. (top) WEST ICRH antenna geometry generated in Petra-M from CAD file; (bottom)Mesh of the antenna adopted in the simulations.

Figure 3 compares two 3D ICRH simulations for 40-degree WEST torus using different mesh size. The left (right) figure shows E_z field on the midplane with a 3.5cm (1.7 cm) mesh size and the 2nd order FEM elements, which corresponds to about 7M DoFs (17 DoFs). Reasonable agreement between two simulations indicates that these wave field solutions are nearly converged and the mesh size is sufficient. Comparison between Petra-M 3D ICRF simulations on WEST with experimental data in terms of antenna coupling / loading is currently in progress and the initial results agree well with the data. Also, note that in these simulations, the cold plasma approximation is used, which may not be accurate enough when considering the interaction between multiple antennas. As a next step, we plan to (i) simulate a larger plasma domain in order to consider two or all three ICRH antennas; (ii) couple Petra-M antenna simulation with TORIC to be able to evaluate self-consistently both core and edge damping.

As for the LH simulations, figure 4 (left) shows the LH wave field with power injection from the top row of the antenna only. In these simulations, an electron density measured by reflectometer installed on WEST was employed. The core density is about 0.8 x 10^{19} m^{-3}. The figure shows both the reverse and forward direction of the wave field. Figure (right) shows the wave field amplitude at the center of the launcher, showing a possible coupling between adjacent rows. Moreover, the radial component of the wave field is found to be twice the poloidal component (figure 5(a)). These initial LH 3D simulations show that we can handle the full geometry size and we can perform a direct comparison with DSELF diagnostic [4, 5]. Comparison between Petra-M are ALOHA [6] for the LH coupling calculations is underway.

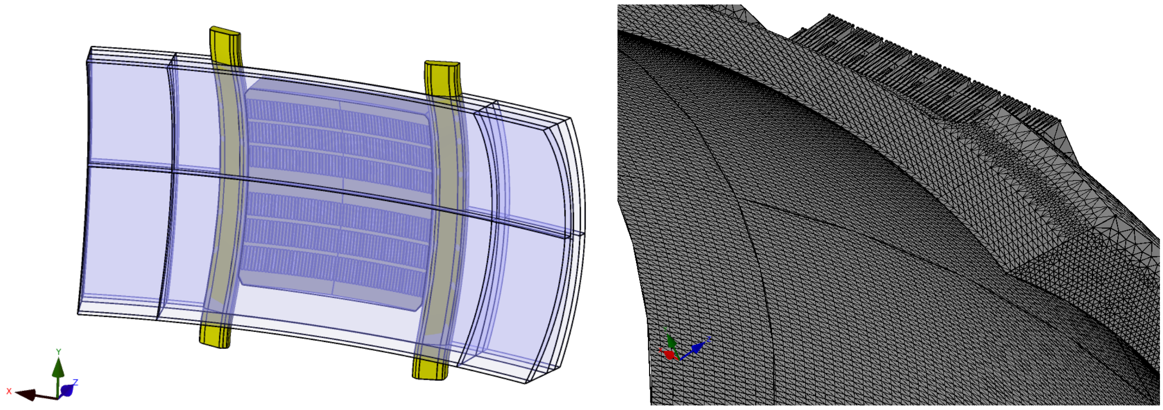

Figure 2. (a) WEST LH antenna geometry generated in Petra-M from CAD file; (b)Mesh of the antenna and the plasma region in front of the antenna adopted in the simulations.

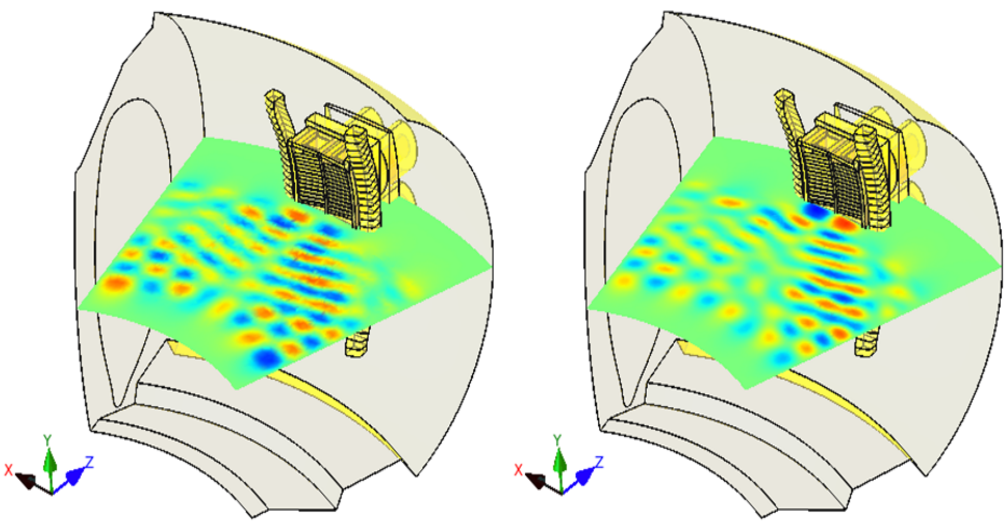

Figure 3 Fast wave (E_z) excited by an IC antenna.

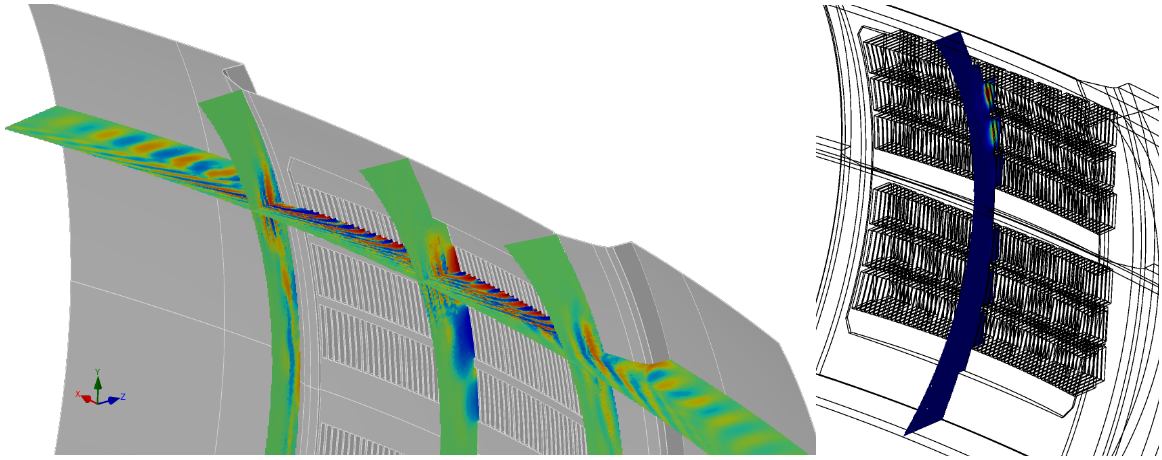

Figure 4 (Left) E_{tor} of LH waves launched from the top row of LH1 launcher and (right) $|E_{tor}|$ in the poloidal cross section in the middle of the antenna.

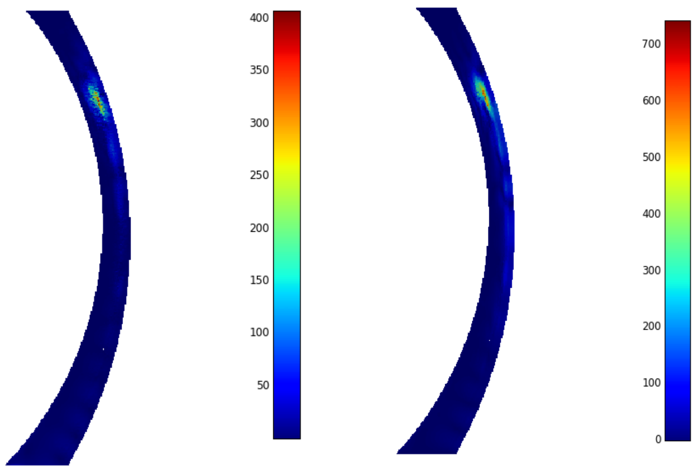

Figure 5 $|E_z|$(left figure) and $|E_{rad}|$(right figure) evaluated in front of side limiter.

Acknowledgments

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