§10. Design and Analysis of RF Heating and Current Drive Antenna System

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Electron Bernstein wave heating and plasma-current drive (EBWH and EBWCD) is one of attractive candidates of heating and current drive method to sustain the steady-state plasma in the spherical tokamak (ST). The Q-shu University Experiment with Steady State Spherical Tokamak (QUEST) was proposed at Kyushu University, and the QUEST tokamak was constructed. The establishment of steady-state current drive method is a key issue to study plasma-wall interaction phenomena in the steady-state QUEST plasma. In the O-X-B mode conversion, the beam is obliquely injected to the plasma with an optimum refractive index $N_{//}$ in parallel to the magnetic field. The elliptical (O-mode) polarization and the launching angle should be controlled to attain the high conversion efficiency. The phased array antenna with 8 waveguide elements has been designed using the developed Kirchhoff integral code and the HFSS code. The antenna size were optimized to reduce the unwanted side-lobe component. Figure 1 shows the improvement of the field profile radiated from phased array antennae at the propagating z=0.1m position. The side lobe components were significantly reduced inn the improved antenna. Figure 2 shows the power spectrum for the refractive indexes, of the toroidal and poloidal components, excited at the improved-antenna aperture. The spectrum was calculated from 2 dimensional Fourier integrals with the specific refractive indexe. The incident beam can be controlled with good directivity in accordance with the experiment requirement in the O-X-B mode conversion scenario, in particular to the toroidal direction.

In the steady-state operation, the heat generation due to the high power transmission should be removed by forced water-cooling. The increment of temperature, and thermal stress were analyzed using the HFSS/ ePhysics/ ANSYS codes. The total power of 200kW was transmitted at the antenna in CW operation. In the first antenna structure, the maximum antenna temperature reached to 94 degrees C. Figure 3 shows the increased temperature distribution of the first antenna structure in the CW operation. If the oxygen-free copper of the antenna material is annealed in the brazing process, the yield point stress is dramatically reduced. The analyzed thermal stress transgressed the yield point stress to cause permanent sets [1]. The electron beam welding technique was adopted to fabricate the antenna instead of the brazing process. The antenna structure was also changed to improve the cooling efficiency. Figure 4 shows the increased temperature distribution at the improved-antenna in the CW operation. The maximum temperature of the antenna was 67 degree C, and the thermal stress was analyzed to be moderate. The increased temperature and thermal stress in the CW operation was decreased by the improved cooling efficiency. The yield point stress to cause the permanent sets was also increased by the rethink of the fabrication process.

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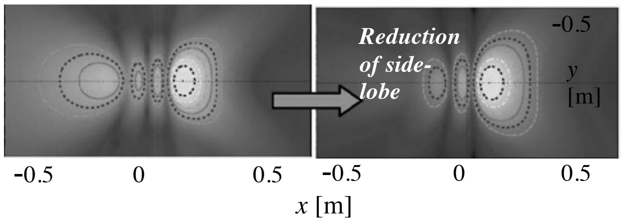

Fig. 1 : Improvement of the field profile radiated from phased-array antenna at the propagating z=0.1m position.

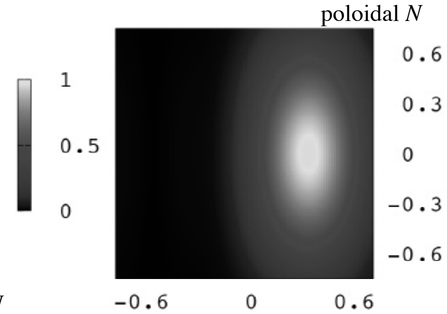

Fig. 2: Power spectrum for refractive indexes excited in the phased array at the antenna aperture.

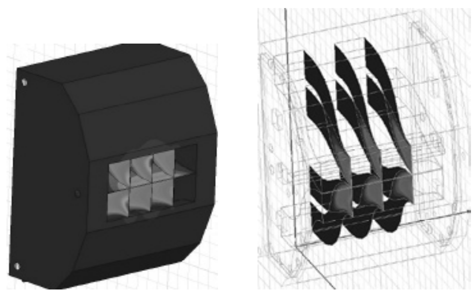

Fig. 3: Increased temperature distribution of the first antenna structure in CW 200 kW operation

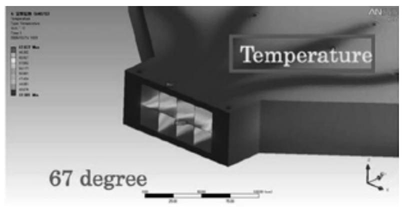

Fig. 4: Increased temperature distribution of the improved antenna in CW 200 kW operation

[1] H. Idei *et al.,* Proc. of the IRMMW-THz 2009, R2D04 (2009).