§27. The Improvement in Steady-state Discharge Using a Toroidal Phasing Antenna in the LHD

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On a steady-state operation by using radiofrequency (RF) wave heating, radiation collapse is a critical issue to prevent a sustainment of the discharge on the Large Helical Device (LHD). The radiation collapse event often happens after strong hot-spots are appeared in vacuum vessel, and then an impurity which is mainly iron goes into core plasma [1]. In order to reduce local hot spots which are caused by RF sheath loading and RF absorption at plasma edge, RF-field around ion cyclotron heating (ICH) antenna has been calculated using by a three dimensional electromagnetic solver "HFSS". A toroidal phasing antenna, a hand-shake form type antenna (a HAS antenna), is designed, and the toroidal phasing antenna is installed in the LHD at 2010 [2].

The toroidal phasing antenna excites several wavenumbers by phasing RF-current on the strap surface, and the antenna shape is re-optimized in order to reduce heat flux to the antenna protector on steady-state discharges. Figure 1 shows the calculation results for the maximum magnitude of E-field on the surface of carbon protectors with a full-scale antenna model which is included actual material and a 1/5 section of LHD with an water plasma as a low plasma density (the electron density n_e is approximately 10^{18} m^{-3}). Comparing with the RF-field between the in-phase and the reverse-phase, the superposition RF-field around the outside protectors, the left side (U-antenna) and the right side (L-antenna) protectors, is small with the reverse-phase. The superposition RF-field with the reverse-phase reduces RF-sheath loading, and these indicate that local heat flux caused by RF-sheath reduces. Large E-field at the edge of top and bottom of the protectors between antennas causes terribly arc damage, and the reverse-phase operation decrease in the magnitude of E-field at the edge of top protectors.

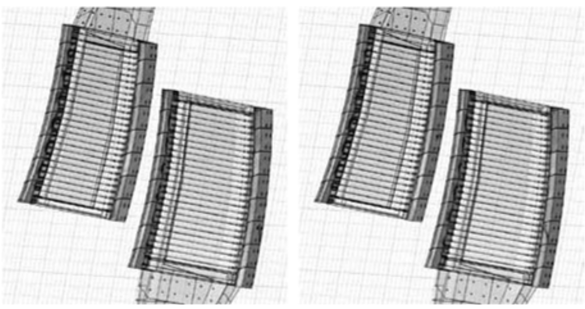
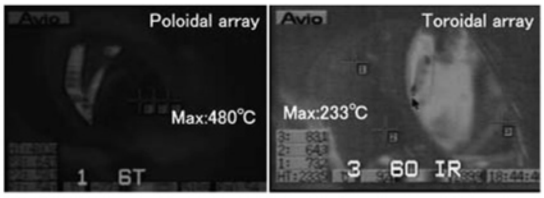


Fig. 1. Calculated maximum magnitude of E-filed by using three dimensional electromagnetic solver, HFSS with in-phase (left) and reverse-phase (right) on the strap currents. Colors on the protectors indicate the magnitude of E-field, and red means large and blue means small.



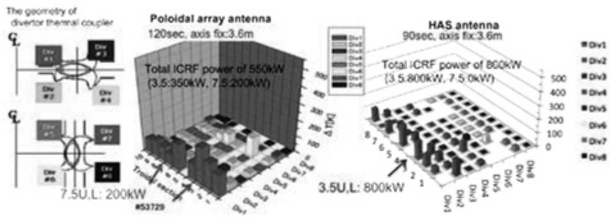


Fig. 2. The comparison with local hot spots on the antenna protectors (Infrared camera) and the increments in thermocouple on divertor tiles between poloidal array antenna and toroidal array antenna. Antenna plasma distances between last closed flux surface and antenna protectors are 12 cm for poloidal array antenna and 7 cm for toroidal array antenna.

On the 14th LHD campaign, the HAS antenna is installed at 3.5U and L port, and initial toroidal phasing antenna experiment has been studied in various phases. Comparing with heating efficiencies between the in-phase and the reverse-phase operations, the heating efficiency with the reverse-phase (~90%) is larger than that with the in-phase (~80%), and the reverse-phase operation is useful to sustain larger electron density plasma [3]. Figure 2 shows the local hot-spots on the antenna protectors and the increments in thermocouple on divertor tiles in the poloidal array antenna [1] and in the toroidal array antenna. The poloidal array antenna has local hot spots on the top of the end of the protectors, and heat flux to local divertor tile is concentrated around the antenna. On the other hand, in the toroidal array antenna operation with the reverse-phase local hot spots are not observed, and the increment of protectors is approximately half because the antenna shape is re-optimized and heat removable ability is improved in order to reduce the temperature of antenna protector. The excited wave using toroidal phasing antenna with the reverse-phase is larger, and the wave can not propagate around plasma edge ($\rho(=r/a) \sim 1$). The heat flux caused by the edge plasma damping is small, and the increment in divertor thermocouple temperature around the antenna is not localized. Then the decrement in local hot spots is achieved by using toroidal array antenna with the reverse-phase. These improvements perform stable steady-state discharges with high density and high temperature.

[1] H. Kasahara, et al., "Control of steady-state operation using ICRF heating in the Large Helical Device", Fusion Eng. and Des. **83,** 253-255 (2008).
[2] H. Kasahara, et al., "An analysis of an ICRF antenna with controllable toroidal wavenumber in LHD", Plasma and Fus. Res. 5, S2090 (2010).
[3] T. Seki, et al., "Dependence of antenna phasing on heating performance in HAS antenna", NIFS annual report (2011).