§4. Newly Designed Controllable Wavenumber Antenna (HAS)

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The Large Helical Device (LHD) has a possibility of attainment of steady-state plasma discharge using stable magnetic structure by only external superconducting coils, and long pulse discharge, 54 min. 28 sec. [1], is demonstrated using ion cyclotron range of frequencies (ICRF) wave heating with the assist of electron cyclotron heating (ECH). The discharge was suddenly terminated by the radiation collapse due to the metal penetration, and the additional ECH could prevent the radiation collapse. The impact of direct accelerated particles in front of ICRF antenna and the sheath loadings are the candidate of the cause [2]. In order to decrease in the sheath loading and the direct acceleration, new ICRF antenna which can excite the waves with the phase difference, 0-0 and 0-π, and which is optimized excited electric field around the antenna, is designed (Fig. 1). The strap is installed to vertically to the magnetic field line in front of the antenna, and it can reduce the parallel electric field $E_{||}$ along the magnetic field line on the last closed flux surface (LCFS). To study the three-dimensional effect of the antenna, electrical magnetic structure around the antenna is calculated using a commercial based electrical magnetic solver (HFSS) with the actual antenna and the vacuum vessel model, and a large permittivity material, $\varepsilon_r \sim 2000$, is substituted for a plasma with the electron density of 5×10^{19} m^{-3}. In figure 2 excited electric field with two kind of phase differences, 0-0 and 0-π phase, is shown, and the calculated electric field $E_{||}$ is negligible (less than 1 kV) near the antenna, and small sheath loading is expected with the 0-π phase excitation. The new ICRF antenna, handshake form antenna (HAS), can control the parallel wavenumber $k_{||}$ using the RF power supply with the phase difference, and the controllable $k_{||}$ on the LCFS (R_{ax} = 3.6m, B_q = 100%, γ = 1.254) is studied in various phase differences. In figure 3 excitable parallel wavenumber is shown in three kinds of phase differences at the frequency of 38.45MHz. These spectrums are calculated by the excited magnetic field on the magnetic field line on the LCFS, and the distance between antenna and plasma is 7 cm which is shorter than the distance between these antennas of HAS. AS Decreased in the phase difference of RF power supply (0-π -> 0-0), the component of low wavenumber is increased, and the component of large wavenumber is decreased. At the phase difference of 0-π/2, excited wavenumber is larger than 0-π, and the intensity of large wavenumber is strong. However, antenna loadings of these strap is large difference, and there are necessary to be additional matching tools such as a decoupler and an advanced matching scheme. Controlling these phase differences, excitable wavenumber is changed from 0-12 m^{-1} with 0-0 phase to 4-10 m^{-1} with 0-π phase, we can control the coupling to direct electron heating using Electron Landau damping and Transit time magnetic pumping.

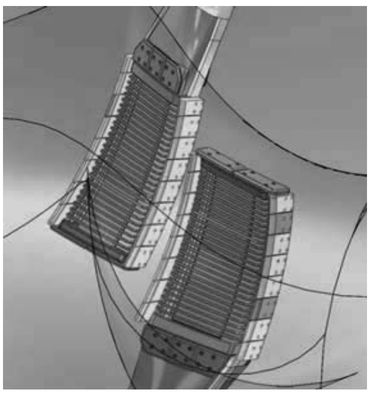

Fig. 1. The picture of newly designed handshake form antenna (HAS) in LHD.

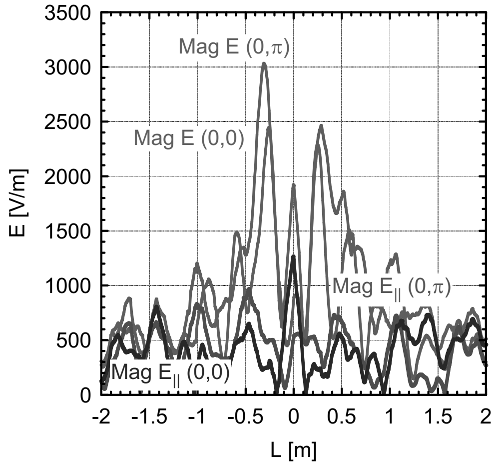

Fig. 2. Amplitude of excited electric field E and the parallel electric filed $E_{||}$ with two kind of phase differences (0-0, 0-π) on the magnetic field line which is through the center of the vertical long cross section. Middle point of two straps is at L=0m, and L means the distance on the LCFS from the middle point.

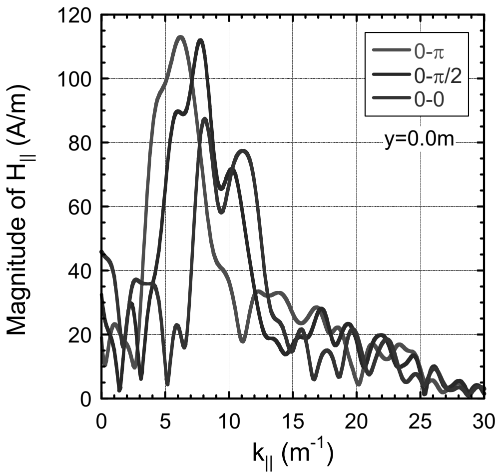

Fig. 3. Excitable parallel wavebvnumber $k_{||}$ in three kind of phase differences on the magnetic field lines in Fig 2. The minimum distance between plasma and HAS antenna is approximately 7 cm, and the gap between these antennas (10cm) is larger than the plasma-antenna

1) T. Mutoh et al.,: *Nucl. Fusion* **47** (2007) 1250-1257.
2) H.Kasahara et al.,: *Fusion Eng. and Design* **82** (2008) 253-255.