

## §17. Initial ICRF Heating Experiments Using Field-Aligned-Impedance-Transforming Antennas in LHD

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A pair of new ion cyclotron range of frequencies (ICRF) heating antennas were fabricated and installed in the large helical device (LHD) for the steady-state and the high power plasma heating as shown in Fig. 1. The features of the antennas are field-aligned structure in the antenna head and the impedance transformer inside the transmission line between ceramic feed-through and antenna head. Therefore, we named the new antennas Field-Aligned-Impedance-Transforming (FAIT) antennas. These antennas are designed based on hand-shake form (HAS) antennas in LHD, which showed high heating efficiency in minority ion heating at the  $0-\pi$  current phase<sup>1)</sup>. The main differences of antenna heads are length and thickness in center strap. The length is about half of that in HAS antenna in order to reduce voltage on the strap since high voltage or electric field leads arcing. The thickness is twice compared to that in HAS antenna in order to reduce the convergence of electric field on the edge of strap. The loading resistance of FAIT antenna was deduced to be low since the loading resistance of HAS antenna is low and the head of FAIT antenna is shorter than that of HAS antenna. In order to increase the loading resistance, impedance transformer was designed using the optimization method<sup>2)</sup>. Two heads of HAS antennas are aligned in toroidal direction in order to increase the wave number parallel to the magnetic field line. However, heads of FAIT antennas are aligned in poloidal direction to avoid NBI armor tiles. Distance between loops of FAIT antennas is large in order to reduce mutual coupling for easy impedance matching. Heads of HAS antennas are tilted by  $12^\circ$  to reduce the electric field parallel to magnetic field line, which causes the formation of RF sheath. However some Faraday shields are crossing the magnetic field lines. On the other hand, FAIT antennas have perfect field-aligned structure.

To investigate the performance of impedance transformer, we compared loading resistance of HAS antenna and FAIT antenna by injecting RF power into the helium plasma with hydrogen minority ions. The loading resistance of FAIT antenna was 2.5 to 3 times higher than that of HAS antenna in spite of the shorter strap length as shown in Fig. 2. Another purpose of the impedance transformer is the protection of ceramic feed-through. We compared temperature on ceramic feed-throughs between HAS and FAIT antennas during long pulse operation. Temperature of FAIT antenna was about one third of that in HAS antenna, where the temperature on HAS may under-estimated since thermo-coupler locates beneath the cooling channel. Electromagnetic field in the transmission line was simulated with HFSS code using experimental antenna impedance. The voltage on the feed-through was low and any convergence of electric field was not seen.

The loading resistance of  $6 \Omega$  was attained by increasing electron density more than  $2 \times 10^{19} \text{ m}^{-3}$  with the standard antenna position where the shape of antenna head was designed and the distance between Faraday shield and last closed flux surface is 5.8 cm. Heating efficiency was estimated by using the power modulation. It reached 85 % when the minority ion ratio was properly adjusted. When the current phase between antenna loops was swept by  $360^\circ$ , power reflection ratio was less than 10 % without impedance matching. This means that mutual coupling between antenna loops is low enough for easy impedance matching. Present maximum injected power per one antenna is 1.13 MW for short pulse. This is limited by the output power of transmitter. The transmission line voltage of 38.5 kV was achieved, which means that the high injection power of 1.78 MW will be possible with the loading resistance of  $6 \Omega$ . Then the power density will reach  $15 \text{ MW/m}^2$ .



Fig. 1 FAIT antenna in LHD

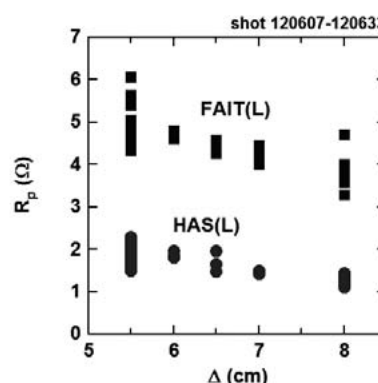


Fig. 2 Comparison of loading resistances between HAS and FAIT antennas

1) H. Kasahara, et al. : Proc. 38<sup>th</sup> EPS Conf. Strasbourg (2011) P2.099.

2) K. Saito, et al. : Fusion Eng. Des. 88 (2013) 1025-1029.