§23. Development of a Fast Wave Current Drive Antenna

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A fast wave current drive antenna is being developed for LHD, motivated by the need to provide a capability for rotational transform profile control. Stability calculations suggest that it is possible to increase the beta limit and obtain access to the second stability region by controlling the rotational transform profile. Current drive by the ICRF fast wave (magnetosonic wave) is suitable for such a purpose.

The LHD antenna consists of two combline antennas stacked vertically and will be placed on the large major radius side of the torus where the plasma is elongated in the vertical direction [1]. The frequency of operation is chosen to be in the neighborhood of 80 MHz, with a bandwidth of about 10 MHz. Electron Landau damping of the fast wave will be used to heat electrons and to drive plasma current. In addition, second harmonic heating of hydrogen ions is also possible at a magnetic field of around 2.6 T.

The antenna is divided into 10 nearly identical modules for ease of fabrication and adjustment. Each module consists of the upper and lower straps (with the grounded ends on the midplane), a backplate, and a U-shaped Faraday shield. Ten of these modules are placed side by side in the toroidal direction, following the helical shape of the plasma surface. The spacing between adjacent straps (center to center) is 0.11 m, which corresponds to a wavenumber of 14 m^{-1} when the phase difference between adjacent current straps is 90°. The antenna is surrounded by carbon protection tiles arranged in a "picture frame" configuration.

A prototype antenna, consisting of 4 modules of the LHD antenna, were assembled at the University of Tokyo, and its electrical characteristics were measured. Since the first and the last elements only have one neighboring element on one side, they are different from other elements, and adjustments must be made to ensure a clean bandpass characteristic of the combline antenna. Extender elements were added to either the end elements or the middle elements to adjust the length of the straps (and therefore their inductance and capacitance). The radiation resistance in the presence of the plasma was simulated by placing a resistive film in front of the antenna. The intensity and the phase of the RF magnetic field (toroidal component) in front of the Faraday shield were measured using a loop probe, approximately 1 cm in diameter. Based on these measurements, the "back Faraday shield" was eliminated.

Matching from the feeder to the antenna was improved (the reflection within the passband decreased from –5 dB to –15 dB) by adopting a direct feeding method instead of the loop coupling method. The top row and the bottom row can be excited either in phase or out of phase (or their linear combination). In order to excite the in-phase mode predominantly, a coupling loop linking the top row and the bottom row was added to the first and the last elements. This has enabled approximately (but not perfectly) in phase excitation of the top and bottom rows. A clean bandpass characteristic of the antenna with a 10 dB bandwidth of over 10 MHz centered around 74 MHz was obtained by adjusting the feeder position.

A test with plasma load was performed on the TST-2 spherical tokamak at the University of Tokyo using a 6-strap combline antenna with a passband (defined as the frequency range where the transmission is greater than –10dB) of 22-28 MHz. A low-power (1 kW level) high-harmonic fast wave (HHFW) was excited. At 25MHz (approximately 8th harmonic of the hydrogen cyclotron frequency) the excited toroidal wavenumber is 13 m^{-1} at $R = 0.57$ m, which corresponds to a toroidal refractive index of 25 and a toroidal mode number of 7.4. The loading resistance was so high that rf currents induced in the second strap became much smaller than that in the first strap. The loading resistance decreased when the density at the antenna was reduced by inserting a movable limiter beyond the antenna radius. This argues for installing the antenna sufficiently far away from the plasma in order to ensure wave excitation with high directivity.

RF magnetic fields were measured by magnetic probes located on the low field side of the torus near the midplane. The measured phase shifts were consistent with the excited toroidal mode numbers of 7-8. A broadening of the frequency spectrum is observed when the plasma is present, which suggests scattering of the incident HHFW by low frequency density fluctuations. [2].

During the next fiscal year, final adjustments of the input and output straps will be made based on measurements of the complete LHD antenna with 10 straps.

References

[1] Takase, Y., et al., in Annual Report of National Institute for Fusion Science April 1999 – March 2000, p. 244 (2001).

[2] Ono, M., et al., in Proc. 14th Conf. RF Power in Plasmas (Oxnard 2001), paper A38 (proceeding to be published, 2001).