§9. RF Plasma Generation and Current Ramp-up Experiments on the TST-2 Spherical Tokamak

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The purpose of this collaborative research is to perform plasma generation and plasma current ramp-up experiments using radiofrequency (RF) waves on the TST-2 spherical tokamak. This research aims at establishing the scientific basis for RF plasma generation and plasma current ramp-up in spherical tokamak (ST) plasmas, with the eventual objective of developing an innovative method for realizing high-performance high-β plasmas.

The TST-2 spherical tokamak at the University of Tokyo is a major ST device in Japan, with R = 0.38 m and a = 0.25 m (aspect ratio R/a = 1.5). It has already achieved toroidal magnetic fields of up to 0.3 T and plasma currents of up to 0.14 MA. TST-2 has the advantages of ample experimental time and flexibility with short turn-around time for hardware modifications. RF power of up to 400 kW in the frequency range 10–30 MHz is available for heating and current drive by the high-harmonic fast wave (HHFW). In addition, four transmitters with output powers of 100 kW each at 200 MHz, previously used on the JFT-2M tokamak, are in operation. This frequency is suitable for testing plasma current ramp-up by the lower hybrid wave (LHW). Plasma generation and plasma current ramp-up experiments using a travelling wave in the lower hybrid frequency range have started under collaboration between the University of Tokyo RF group and the NIFS RF group.

In FY 2009, the output powers of two transmitters were connected to the two-strap loop antenna, previously used for the 21 MHz HHFW heating experiment (Fig. 1). RF powers exceeding 100 kW have been delivered to the plasma through this antenna. Preliminary experiments were performed using the two-strap loop antenna, but this antenna cannot excite a uni-directional travelling wave necessary for current drive.

Fig. 1. Photograph showing the coaxial transmission lines to deliver RF power from 200 MHz transmitters to the two-strap loop antenna installed inside TST-2.

The combline antenna makes use of mutual coupling between adjacent loops, and is suitable for exciting a travelling wave. The combline antenna used previously on the JFT-2M tokamak was modified for use on TST-2. The TST-2 combline antenna consists of an array of eleven-element quarter-wave resonant loops coupled by mutual inductance. A major advantage of the combline antenna is that only the edge element needs to be excited externally. Furthermore, since the input impedance of the combline antenna is close to 50 Ω, the standing wave ratio is small and the maximum voltage in the transmission line can be kept low. In FY 2010 the combline antenna was installed in TST-2 (Fig. 2). Plasma generation and plasma current ramp-up to over 10 kA were achieved using this antenna. This is the first experimental demonstration of ST plasma start-up using waves in this frequency range. In addition, an asymmetry in the achievable level of plasma current with respect to the direction of the excited travelling wave (co vs. counter current drive direction) was observed, suggesting the importance of directly driven current relative to the pressure gradient driven current.

Preliminary ion heating experiments using the beat wave were performed by injecting waves with slightly different frequencies (200.1 MHz and 199.6 MHz) from the two ends of the combline antenna.

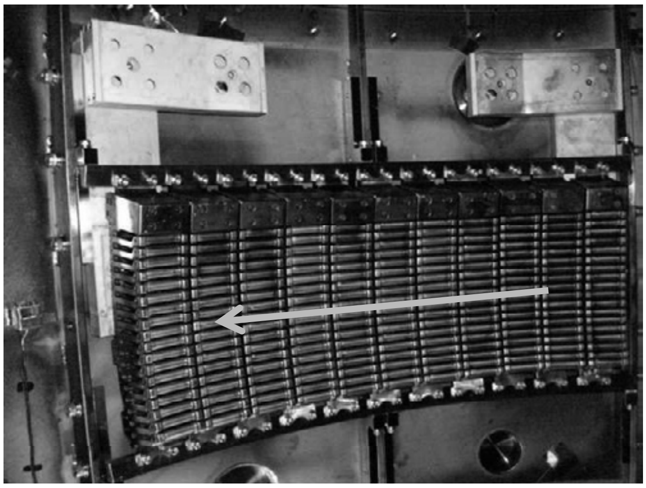

Fig. 2. The combline antenna installed inside TST-2. RF power is fed from one end of the antenna array, propagates to adjacent elements sequentially, and the power not radiated into the plasma exits from the other end.

1) A. Ejiri, et al., "Non-inductive Plasma Current Start-up Experiments in the TST-2 Spherical Tokamak," 23rd IAEA Fusion Energy Conf. (Daejeon, Korea, Oct. 11-16, 2010).
2) H. Kakuda, et al., "200MHz Fast Wave Experiment using a Combline Antenna in the TST-2 Spherical Tokamak," US-Japan RF Physics Workshop (Toba, Japan, Feb. 8-10, 2011).
3) T. Wakatsuki, et al., "Plasma Start-up Experiments in TST-2 and Direct Measurement of HHFW Field Profile in UTST," US-Japan RF Physics Workshop (Toba, Japan, Feb. 8-10, 2011).