§13. Study on Tokamak-helical Hybrid Configurations with a Low Aspect Ratio

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The TOKASTAR-2 is a small toroidal device in which plasma confinement with tokamak configurations, stellarator configurations and tokamak-stellarator hybrid configuratins are possible[1,2]. The main objectives of this device are to evaluate effects of helical field application on tokamak plasma and to study effects of the plasma current on compact stellarator configuration. The pulsed vertical field (PVF) coils and the additional helical field (AHF) coils were installed in FY 2011. The capacitance and charging voltage of capacitors for PVF coils were determined to realize the optimal PVF coil current waveform by analysis using the circuit simulator LTspice in FY 2013[3].

In FY 2014, optimization of tokamak operation, application of helical field to tokamak plasmas, evaluation of eddy current in the vacuum vessel and Langmuir probe measurement of helical plasmas were performed.

In optimization of tokamak operation, detailed scan of PVF coil current was done. The radial position of plasma is limited between R = 0.065 m and R = 0.180 m by inner and outer legs of toroidal field coils located inside the vacuum vessel. Our objective was to find conditions in which tokamak plasma is sustained at a larger major radius, close to the helical field located outside, to enhance effects of helical field. Nitrogen (N_2) was used as working gas instead of helium (He) because better reproducibility of tokamak discharge was found in N_2 operation. A new record of plasma current (2.5 kA) was achieved at high PVF coil current. The peak plasma current was 2.2 kA when the PVF coil current was adjusted to maximize the plasma current duration (0.45 ms). The radial movement of plasma was studied by a high-speed camera typically with 60,000 frames per second[4]. Since the field of view was limited up to R = 0.115 m by an outer leg of a toroidal field coil, plasma movement at a larger major radius was not clearly obtained.

The plasma center position was estimated by the radial profile of poloidal magnetic field measured by multi-channel magnetic probe array (10 channels)[5]. It was observed that the plasma center was located at R < 0.12 m and the last closed flux surface was touched to the inboard wall during the discharge when the PVF coil current was adjusted to maximize the plasma current duration.

The helical field was applied to tokamak plasmas. The currents in the helical field coils were those that would form vacuum closed flux surfaces. The plasma current 40 μs after the breakdown increased for a wide range of PVF coil current values, which suggests positive effect of helical field on tokamak plasma initiation. Oscillation in the plasma radial position observed for small PVF coil current was suppressed by applying the helical field. This suggests the stabilization effect of the helical field on the radial plasma movement.

Langmuir probe measurement was done for the case that closed flux surfaces were expected to be formed with the helical field coil current and the vertical field coil current and without plasma current. Figure 1 shows time evolution of electron temperature measured by the single probe method. A 2.45 GHz RF wave was injected for plasma heating and its fundamental resonance layer (0.0875 T) was located inside the expected closed flux surface during the period between two dotted vertical lines. Increase in the electron temperature in the case with expected closed flux surface was observed. However, the measurement point was located at Z = -0.045 m for Fig. 1 and no clear effect of helical field was observed in the measurement at Z = 0.00 m. This seems to correspond to the fact that the intense light was located below the equator plane in the high-speed camera images[4]. On the other hand, the magnetic field tracing indicates closed flux surfaces would be formed slightly above the equator plane. The position of closed flux surface would be affected by error fields. It is planned to evaluate the structure of magnetic surfaces by using electron beam.

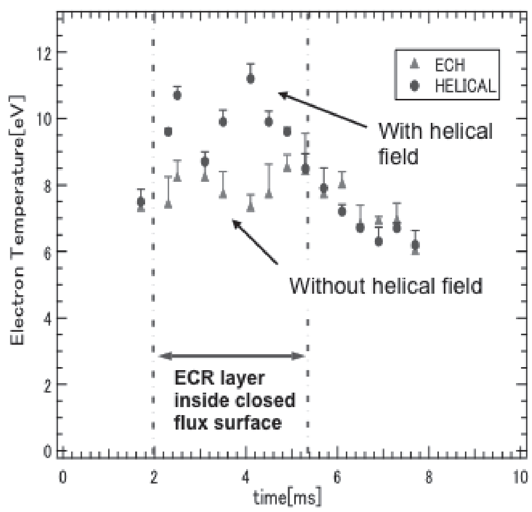

Fig. 1. Time evolution of electron temperature measured by a single probe. The blue circles denote the case with helical field and the red triangles denote the case without helical field.

1) Oishi, T. et al.: J. Plasma Fusion Res. SERIES **9** (2010) 69.
2) Oishi, T. et al.: J. Physics: Conf. Series **511** (2014) 012042.
3) Nishimura, R. et al.: Plasma Fusion Res. **9** (2014) 3402059.
4) Sakito, T. et al.: Plasma Fusion Res. **10** (2015) 3402033.
5) Ueda, T. et al.: Plasma Fusion Res. **10** (2015) 3402065.