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Development of Multi-Frequency Mega-Watt Gyrotrons for Fusion Devices in JAEA

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Mega-watt gyrotrons with frequency tuning have become essential devices in fusion science to perform effective EC H&CD. JAEA is developing two types of multi-frequency gyrotrons equipped with a triode magnetron injection gun for ITER and JT-60SA. A TE_{31,11} mode, which is a candidate mode for 170 GHz oscillation, has sufficient margin for cavity heat-load in 1 MW operation, and it has a great advantage for multi-frequency oscillation. In the JT-60SA project, EC H&CD by second harmonic EC waves are planned using nine sets of 110 GHz/138 GHz dual-frequency gyrotrons to broaden the experimental research area. In FEC2014, demonstrations of 1 MW oscillations for 2 s at 170 GHz/137 GHz/104 GHz with the ITER gyrotron and achievement of 1 MW oscillations for 100 s at 110 GHz /138 GHz in the JT-60SA gyrotron were reported as world records. After FEC2014, oscillation methods to improve the efficiency at 170 GHz for ITER requirements and higher frequency oscillation for the demo-class reactor were investigated. For the JT-60SA gyrotron, the operation area was expanded to surpass maximum performance (1.5 MW/4 s) of the previous JT-60 110 GHz gyrotron. TE_{31,11} mode oscillations were often prevented by adjacent counter-rotating (ctr-) modes such as TE_{29,12}, and TE_{28,12} modes. By introducing active anode-voltage control and beam-radius control to suppress adjacent counter-rotating modes, start-up of TE_{31,11} mode becomes stable and the overall efficiencies achieved ~ 50 % up to 1.1 MW.

In looking ahead to a future gyrotron for the demo-class reactor, 203 GHz oscillation of higher-order volume mode (TE_{37,13}) was performed for the first time by taking advantage of the multi-frequency gyrotron feature. In preliminary testing at 203 GHz, 0.9 MW for 0.3 ms and 0.42 MW for 5 s were demonstrated. ITER gyrotron having mega-watt-class power at four frequencies in wide range over 100 GHz was developed.

High power gyrotron development toward 1.5 –2 MW oscillation for several seconds has been carried for further extension of the experiment regime of high performance plasma in JT-60SA. In a test conducted in 2015, achievements of 1.8 MW/1.2 s at 110 GHz (TE_{22,8} mode) in non-coaxial type gyrotron and high-power oscillation of 1.3 MW/1.3 s at 138 GHz (TE_{27,10} mode) and 1 MW/1 s of 82 GHz (TE_{17,6} mode) have been demonstrated as a new world record.

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