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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 TE31,11 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. TE31,11 mode oscillations were often prevented by adjacent counter-rotating (ctr-) modes such as TE29,12, and TE28,12 modes. By introducing active anode-voltage control and beam-radius control to suppress adjacent counter-rotating modes, start-up of TE31,11 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 (TE37,13) 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 (TE22,8 mode) in non-coaxial type gyrotron and high-power oscillation of 1.3 MW/1.3 sat 138 GHz (TE27,10 mode)and 1 MW/1 s of 82 GHz (TE17,6 mode) have been demonstrated as a new world record.

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Author: Dr IKEDA, Ryosuke (Japan Atomic Energy Agency)

Co-authors: Dr SAKAMOTO, Keishi (Japan Atomic Energy Agency); Dr KAJIWARA, Ken (Japan Atomic Energy Agency); Dr TAKAHASHI, Koji (Japan Atomic Energy Agency); Dr MORIYAMA, Shinichi (Japan Atomic

Energy Agency); Dr KOBAYASHI, Takayuki (Japan Atomic Energy Agency); Dr ODA, Yasuhisa (Japan Atomic Energy Agency)

Presenter: Dr IKEDA, Ryosuke (Japan Atomic Energy Agency)

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