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[REGULAR POSTER TWIN] Progress on performance tests of ITER-gyrotrons and design of dual-frequency gyrotron for ITER staged operation plan

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This paper presents a progress of the achievement of performance tests of ITER-gyrotrons developed in QST and design of dual-frequency (170 GHz and 104 GHz) gyrotron to enhance various operation scenarios in ITER such as characteristics studies of H-mode/ELM at low magnetic field. Major achievements of the ITER gyrotron developments are as follows: (i) Manufacturing of 6 out of 8 sets of ITER gyrotrons was completed. Factory acceptance test (FAT) in QST has been progressed and 2 of 6 gyrotrons achieved required specifications such as 1 MW / 300 s / 50 %, 5 kHz modulation with ≥ 0.8 MW etc. The 50 mm diameter waveguide transmission-line and a matching optics unit (MOU) for ITER were newly introduced to perform the operation test at the same environment as ITER-site and excitation of HE11 mode purity of ≥ 95 % at the waveguide inlet was also successfully demonstrated, satisfying the requirement. (ii) Design of dual-frequency gyrotron, which is able to operate continuous wave of 1 MW power, was successfully completed.

Introduction

An ITER electron cyclotron heating and current drive system will be installed for initial breakdown, assist of electron heating during current ramp-up, on/off-axis current drive for the steady-state operation, plasma instability control using 24 sets of 170 GHz gyrotrons. The required specifications of the ITER gyrotron are 1 MW/continuous wave (CW) with efficiency of 50% and 5 kHz modulation capability with ≥ 0.8 MW. The QST procures eight sets of the gyrotron and four of them are planned to be used for first plasma. Six gyrotrons have been manufactured in the period of 2016 ~ 2019. In FEC2018, FAT results of a first ITER gyrotron were reported [A]. After the first plasma phase, low field operation at 1.8 T is being considered to evaluate threshold power for a H-mode. If the H-mode plasmas are generated, some issues such as a validity of L-H scaling, an ELM control and divertor heat loads will be demonstrated in early stage. The 1.8 T operation desires ~100 GHz RF for plasma breakdown, ramp up, heating and current drive in second harmonics and 170 GHz in third harmonic. In the QST, the multi-frequencies 1MW oscillation at 104 GHz / 137 GHz / 170 GHz / 203 GHz were demonstrated using a proto-type ITER gyrotron [B] However, the pulse length was only a few seconds for 104GHz and 137GHz. The design study of a dual frequency (104 GHz and 170 GHz) gyrotron to achieve long pulse operation of 1 MW power has been carried out in 2019.

(i) *Operation performance tests of ITER gyrotrons*

The FAT of the 2nd ITER gyrotron was completed in 2019. The output power of 1.05 MW and total efficiency of 50.6 % in the long pulse operation was achieved. The oscillation frequency was 169.85 GHz. 20 similar operations were repeatedly performed 20 times with 25 % duty cycle and the operation reliability of 95 % was demonstrated. In 5 kHz full-power modulation, the maximum output power of 0.90 MW was achieved. As summarized in Fig.1, the 2nd gyrotron demonstrated the same performance as the 1st gyrotron.

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The FAT of two gyrotrons were carried out using a prototype MOU and 63.5 mm diameter waveguides, which were assumed in the previous specifications. The integrated test introducing ITER relevant waveguides (50 mm diameter) and the MOU was carried out for the third gyrotron to simulate the operation at the ITER-site. As shown in Fig.2, a parabolic mirror and a phase-correction mirror in the MOU were newly designed to focus the beam size and flatten the phase of electric field at the waveguide inlet. It was shown that the mode purity of HE11 exciting at the waveguide inlet was 95.5%, which was comparable to the design value of 96.1 %. The power transmission efficiency in the MOU was 95.5 %, which was equivalent to the design value. These results satisfied the ITER requirement. At present, the 3rd ITER gyrotron is under commissioning and the output power of 1 MW for 100 s has been already achieved.

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(ii) *Design optimization of dual-frequency gyrotron of 170 GHz and 104 GHz*
Issues for improving operation performance at 104 GHz were RF loss scattered in the gyrotron, which was about three times larger than at 170 GHz, and the spread of RF-sidelobe. To achieve the lower loss-power at 170 GHz and 104 GHz, Gauss mode content and directivity of radiated beam at an aperture of internal mode converter must be improved by modifying the inner wall-surface of the mode converter. In addition, a beam power distribution larger than -20 dB, which has non negligible power-level, should also be within the window aperture by modifying the curvature and the tilt of internal four mirrors located above the mode converter. As the results, the Gauss mode content achieved 95.4 % (170 GHz) / 97.5 % (104 GHz), much better than the ITER gyrotron, which are 94.5 % (170 GHz) / 90.7 % (104 GHz). These power transmission efficiency in the gyrotron achieved 98.8 % comparable to the design of ITER gyrotron. Both beams pass through the window center and are within -20 dB as shown in Fig.2. Moreover, two mirrors in the MOU were designed to improve the effective coupling of the beams to a 50 mm-diameter waveguide. Since the discrepancy of radiation angles at the window becomes only 0.1 ° by design optimization of the mode converter, the same MOU mirrors for both beams are applicable. The coupling efficiency from Gaussian to HE11 mode of 95.6 % (170 GHz) and 96.1 % (104 GHz) has been obtained. As shown in Fig.2, the total transmission efficiency between the mode converter and the waveguide inlet is 95 % (170 GHz) / 93 % (104 GHz), higher than the ITER gyrotron design of 94 % (170 GHz) / 81 % (104 GHz). The blank circles in the Fig.3 represent the experimental power transmission efficiencies at the mode converter, at the output window, and at the waveguide. The experiment agrees with the design within error of 1-2%, it shows that the new design promises the long pulse, 1 MW operations at both 170 GHz and 104 GHz.

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Conclusion
Manufacturing of 6 sets of ITER gyrotrons and FAT of 2 sets were completed. The output power of 1 MW with the efficiency of 50 % for 300 s operation and fast power modulation of 0.9 MW for 60 s were achieved. New MOU demonstrated HE11 mode purity of 95.6 %. The design of a dual-frequency (104 GHz and 170 GHz) gyrotron comparable to the same performance as the current ITER gyrotron was successfully completed.

References
[A] Y. Oda, *et al.*, Nuclear Fusion 59 086014 (2019).
[B] R. Ikeda, *et al.*, J Infrared Milli Terahz Waves 38, 531 (2017).

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