First performance test of multi-frequency gyrotron for ITER and fusion devices

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Multi-frequency gyrotrons can selectively generate a high power millimeter-wave at one of the frequencies. One of the advantages of using the multi-frequency gyrotrons on ITER and fusion devices is that the electron cyclotron heating location in plasma is adjustable by using the multi-frequency injection. It will compensate for an injection angle limitation of the launcher caused by the design limitations in 3-D space and in a neutron flux on the components. For such purpose, the multi-frequency gyrotron at 170, 203, and 236 GHz was developed by modifying the ITER prototype gyrotron. In the first performance test, the wave generations at the three frequencies were successfully demonstrated in the 500kW-3ms operations. Moreover, the output power achieved 1 MW at 236 GHz in the 1 ms operation and 880 kW at 203 GHz in the 100 s operation.

Introduction

The millimeter-waves injected into the plasma are absorbed by electrons where the wave frequency is about same as the electron cyclotron frequency. The electron cyclotron frequency is proportional to the magnetic field so that the requested gyrotron frequency also proportionally increases with that. The gyrotron frequency for ITER is 170 GHz [1], which is highest requested frequency in fusion devices. For future fusion devices with stronger magnetic field, the gyrotron frequencies are expected to be higher than 200 GHz [2]. According to the background and the advantage of using multi-frequency, QST started the development of the multi-frequency gyrotron at 170, 203, and 236 GHz.

Design

As a first step, the ITER prototype gyrotron was modified to demonstrate the multi-frequency operation at high power. The design will be improved step-by-step to achieve 1 MW of output power in the continuous wave with high oscillation efficiency of about 30%, such as 170GHz-gyrotron for ITER. For that purpose, the magnetron injection gun (MIG) of ITER prototype gyrotron was replaced to new one whose shape was redesigned to produce a high quality electron beam at the three frequencies. It is known that ITER gyrotron can generate 104 GHz, 137 GHz, 170 GHz and 203 GHz with specific cylindrical modes at the cavity [3]. These frequencies satisfy the multi-frequency condition described in Ref. 4, which are the high transmissivity at window, same radiation angle at the mode convertor, and close cut off frequency at the cavity. The multi-frequency condition indicated that the 236 GHz can be generated additionally without any changes in shapes of the cavity, mode convertor, mirrors, and thickness of output window. With this design, a heat load on the cavity is about a limit of 2 kW/cm^2 in the case of 1 MW long pulse operation at 236 GHz. It is the highest heat load removable by the present cavity design so that the cavity radius might need to be larger in the next development.

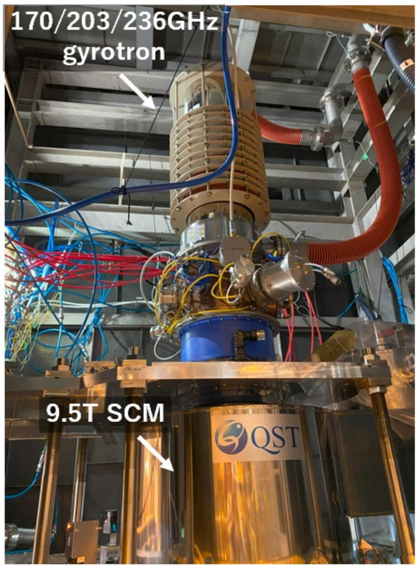

Fig. 1 The multi-frequency gyrotron (170/203/236 GHz) and SCM (up to 9.5 T) newly installed into QST's gyrotron test stand.

Performance test results

The performance of multi-frequency gyrotron was tested by using QST's gyrotron test stand with a new

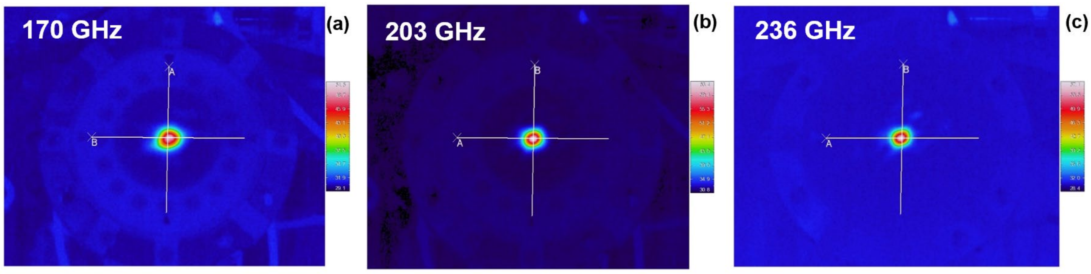

Fig. 2 Measurement of beam patterns at the output window at a) 170, b) 203, and c) 236 GHz.

superconducting magnet (SCM) for the 236GHz-oscillation at around 9.5 T. The SCM was designed by Kyoto Fusioneering and manufactured by JASTEC. The multi-frequency gyrotron successfully generated millimeter wave at 170, 203, and 236 GHz by adjusting the external magnetic field and voltage of each electrode. Those beam patterns were located at center of the output window as shown in Fig. 2. The shapes of beam patterns didn't show any strong sidelobes as expected in the design. These reduce a power loss in a transmission line and a risk of damaging the output window. The high power test was performed with parameters of beam current at 25 A, acceleration voltage at 70 kV, and pulse width at 3 ms. In the test, the output power and oscillation efficiency were about 500 kW and 27-29% at each frequency. The magnetic flux densities at the cavity were 6.58, 7.88, and 9.21 T for the 170, 203, and 236 GHz operations, respectively. Characteristics of output power versus beam current were measured at 236 GHz as shown in Fig. 3. The output power increased with the beam current, and achieved the target value of 1 MW at 65 A in pulse operations for 1 ms. The optimum acceleration voltage became larger with the increase of beam current as shown in Fig. 3. The acceleration voltages were 70 kV at 25 A and 35 A, 75 kV at 50 A, and 78 kV at 65 A. The oscillation efficiency decreased from 27% to 20% with the increase of beam current. The reason is under investigation. In the case of 203 GHz operation, long pulse and high power operations were performed because the power limit in cavity is larger than 1 MW. The 750kW-100s long pulse high power operation was successfully achieved with the oscillation efficiency of 27%. The efficiency was not drastically degraded with the increase of beam current and pulse width. In this campaign, the output power was increased up to 880 kW with 100 s pulse width as shown in Fig. 4.

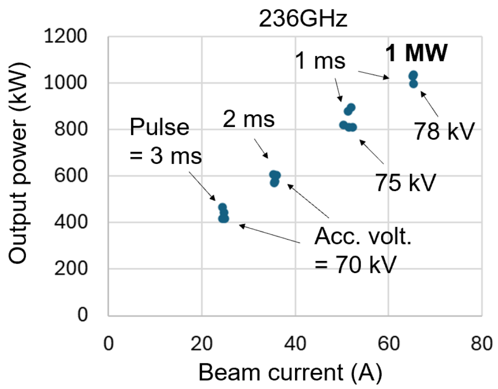

Fig. 3 Characteristics of output power versus beam current measured in short pulse operations at 236 GHz for 1 to 3 ms.

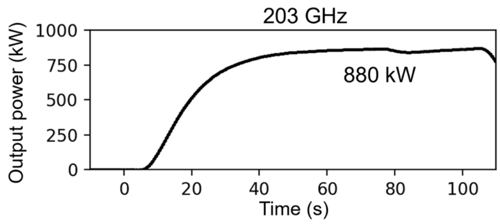

Fig. 4 The output power, measured with a dummy load, achieved to 880 kW in the 100s-operation at 203 GHz. The slow increase in power is due to the calorimetry.

Conclusion

The target of multi-frequency operations at 170, 203, and 236 GHz with high power were successfully demonstrated by modifying the MIG of ITER prototype gyrotron. The output power achieved 1 MW at 236 GHz in the 1 ms operation. Moreover, the pulse width was successfully extended to 100 s at 203 GHz, and the output power achieved 880 kW. These initial results show a possibility of realizing the multi-frequency high power gyrotron for fusion devices.

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