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LHDにおける協同トムソン散乱への適用を目指した
300 GHz帯高出力ジャイロトロンの開発

Development of 300 GHz Band Gyrotron for Practical Use in Collective Thomson Scattering Diagnostics in LHD

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Introduction

Gyrotrons with frequencies around 100 GHz for electron heating are currently used in collective Thomson scattering (CTS) diagnostics [1, 2]. However, the probe waves suffer from severe refraction and/or absorption in plasmas. Moreover, strong electron cyclotron emission becomes a large noise source. Sub-THz waves are almost free from those problems. Therefore, a high power sub-THz gyrotron is required in CTS diagnostics of high density plasmas in LHD. We set the power target of the probe wave higher than 100 kW to obtain a sufficiently large signal to noise ratio. Firstly developed second harmonic gyrotron demonstrated single mode oscillation approaching 100 kW at 389 GHz [3]. However, a competing fundamental harmonic mode prevented to further enhance the power [4]. We have then developed a fundamental harmonic prototype gyrotron and verified the design concept for stable high power oscillation [5]. Based on this successful result, a gyrotron for practical use in CTS diagnostics in LHD has been designed with the same concept as that of the prototype gyrotron and fabricated. High power oscillation test of the practical gyrotron is reported.

Design of and Fabrication of Gyrotron

The sub-THz gyrotron for CTS is operated in a pulse mode. The design frequency is 303.3 GHz. The design concept is the same as that of the prototype gyrotron [5]. A moderately over-moded cavity is used to realize simultaneously single mode oscillation and a low Ohmic loss on the cavity surface. The oscillation mode is the $TE_{22,2}$ mode belonging to the same whispering gallery mode family as the $TE_{14,2}$ mode of the prototype gyrotron. The mode number has increased to extend the pulse width and the duty ratio up to 10%.

Design calculations were carried out about the dependence of the oscillation power and the efficiency on the beam current. For the beam voltage V_k of 65 kV and the beam current I_B of 15 A, oscillation power higher than 300 kW was expected with the velocity pitch factor α of 1.2. A newly designed electron gun was optimized for the $TE_{22,2}$ mode by using the design principle reported in Ref. [6]. Electron beams of high quality with the expected α values and sufficiently small velocity spreads can be generated up to $I_B = 20$ A [7].

Fig. 1. Picture of the fabricated practical gyrotron. A Gaussian beam is radiated through the vacuum window at the left side.

Figure 1 shows the picture of the fabricated gyrotron. This gyrotron is mounted on a liquid He-free 12 T SC magnet. The diameter of the room temperature bore is 100 mm. An internal mode converter composed of a helical-cut Vlasov type launcher and four mirrors is installed into a rather narrow room. Performance test of the mode converter is also an important task of the present study. The vacuum window is made of a c-axis cut crystal sapphire disk. Its thickness is optimized for 303.3 GHz.

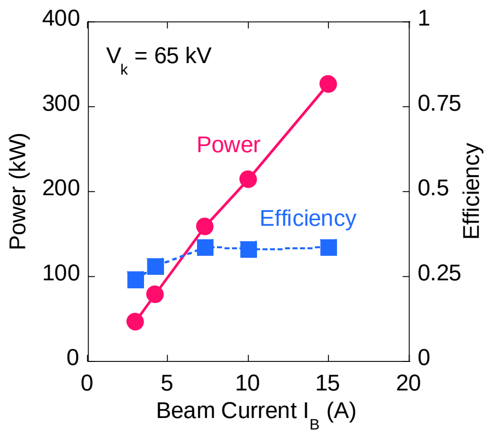

Fig. 2. Output power and efficiency as functions of the beam current. The beam voltage is 65 kV. Other parameters such as the modulation anode voltage are optimized for each beam current.

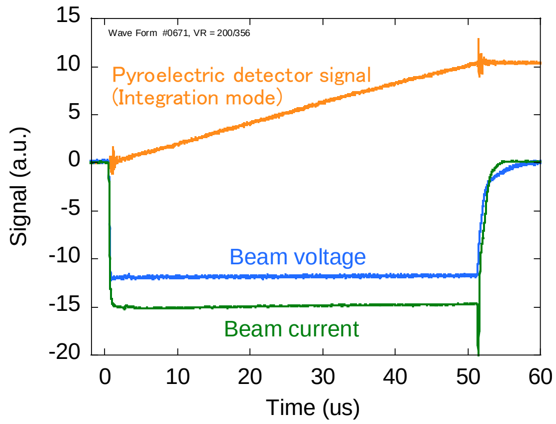

Fig. 3. Oscilloscope traces of a 50-μs oscillation. The beam voltage and the beam current were set at 60 kV and 15 A, respectively. The magnetic field was 11.59 T.

Results of Oscillation Test

Figure 2 plots the results of the high power oscillation test in addition to the already reported data [7]. In particular, the highest power > 320 kW was newly attained. The efficiency is higher than 30% except the low beam current. The obtained powers are consistent with the design calculation with α from 1.1 to 1.3. Further higher power approaching 400 kW is expected with increasing I_B after conditioning.

The radiation pattern was measured with an infrared camera as the profile of temperature increase on a 1 mm-thick polyvinyl chloride plate put in front of the vacuum window A Gaussian like radiation pattern similar to the calculated pattern was obtained. Therefore, good performance of the mode converter was confirmed.

Measurement of oscillation frequency with a Fabry-Perot interferometer showed single mode oscillation around 303 GHz. More accurate frequency measured with a heterodyne receiver system was 303.3 GHz for V_k = 62 kV and the magnetic field at the cavity B = 11.59 T. It is equal to the design frequency within an accuracy of the order of 10 MHz. The frequency variation due to variation of the operation conditions was less than ±100 MHz. This frequency stability is very important for the CTS experiment.

The frequency spectrum was very narrow and stable during the pulse width. Moreover, no possible competing mode was observed throughout the pulse width including the phases of turn on and the turn off of the oscillation pulse. Oscillation other than the $TE_{22,2}$ mode was not observed within a frequency band from 290 GHz to 312 GHz.

Figure 3 represents an oscillation pulse with the pulse width of 50 μs. The output power is about 200 kW. The oscillation signal was measured with a pyroelectric detector in time integration mode. The linear increase in this signal indicates stationary oscillation during the whole pulse width.

Summary

A 300 GHz band pulse gyrotron was fabricated for actual use as a power source of CTS diagnostics in LHD. The results of the oscillation test has confirmed single mode oscillation of the $TE_{22,2}$ mode as the design mode. The measured frequency is almost equal to the design value 303.3 GHz, which corresponds to a minimum of ECE for the standard operation of LHD. The radiated beam has a Gaussian like pattern. More than 320 kW has been obtained.

The oscillation test results have proved that this gyrotron can be practically used in CTS diagnostics in LHD.

Acknowledgement

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