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Development of the high power 170GHz gyrotron for ITER

ITER用170GHz大電力ジャイロトロンの開発

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A high power 170GHz gyrotron has been developed in JAEA for ITER. Two recent topics are introduced. The first is an anode voltage modulation for on/off output RF power with a high-speed switch. Full beam current suppression by shorting the cathode and the anode electrodes by the switch is tested. 5kHz modulation is successfully achieved with the power of 1.1MW and 60 sec with full beam current suppression (up to now). The other is the design and the tests of 170/137GHz dual frequency gyrotron with a triode MIG. In short pulse experiments, the maximum power of more than 1.3MW are achieved with high efficiency for both frequencies. For the long pulse experiments, 1MW/5sec and 760kW/60sec for 170GHz are achieved.

1. Introduction

A gyrotron is a high power millimeter wave source that is applied for electron cyclotron heating and current drive (EC H&CD) and plasma breakdown for the fusion devices including ITER. In ITER, a 5kHz modulation of the gyrotron system for ECCD is important in order to suppress a Neo-classical Tearing Mode (NTM). It is also important frequency tunability of the gyrotorn for the fusion devices, which is effective to widen a range of plasma heating position and/or to correspond to the various range of plasma confinement magnetic field. The progress of these two topics on gyrotron development is introduced.

Table I. List of the modulation methods.

Mod. type	Advantage	Disadvantage
1) Turn on/off main switch	Low heat load on the gyrotron collector	Slow modulation speed (<1kHz)
2) Acceleration voltage modulation	High-speed modulation and low cost of the power supply	High heat load on the gyrotron collector
3) Anode voltage modulation (only for the triode MIG)	High-speed modulation and low cost of the power supply	High heat load on the gyrotron collector

2. A 5kHz modulation

The gyrotron has a couple of modulation strategies listed in Table I. As shown in the table, the type 1) is not suitable to adopt the high speed modulation, because the current of the main circuit is several tenth of A, then, heat removal of the main switch could be issue if the turn on/off frequency is too high. Contrarily, 2) and 3) need to handle less than several tenth of mA. It allows high-speed modulation of more than 5kHz. However, the electron beam is not reduced dramatically when the RF is off. In that period, the electron beam is traveled through the cavity to the collector without dumping the energy, which increases the heat load on the collector. By combining the two methods, ITER plans the type 1) for 1kHz / 0-100% power modulation and the type 2) or 3) for 5~kHz / 50-100% power modulation to protect the collector[1].

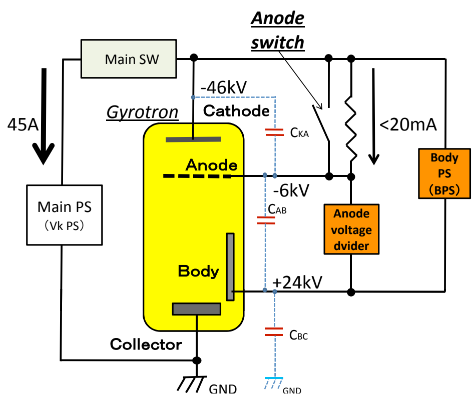

Fig. 1 Modulation circuit with anode switch.

An alternative modulation type for the gyrotron with a triode magnetron injection gun (MIG) is considered for the high-speed modulation with low heat load on the collector by using a short-circuited switch. The electric field around the emission belt on the cathode can be reduced by shorting the circuit between the anode and the cathode electrodes. As a result, the beam current is decreased as close as zero, which decrease the heat load on the collector. The current between the anode and the cathode for CW operation is less than tenth of mA, therefore, the short-circuited switch between the anode and the cathode (=anode switch) can be small compared to the main switch and there is no problem about the cooling even for the 5kHz modulation. The power supply circuit including the newly installed anode switch is shown in Fig. 1.

There is another advantage to suppress the electron beam during turn off phase. Because the heat load on the collector and the cavity are about half in this operation, there is a good possibility to increase the beam current to generate more than 1MW RF power with 1MW CW designed gyrotron. It is very attractive option for ITER.

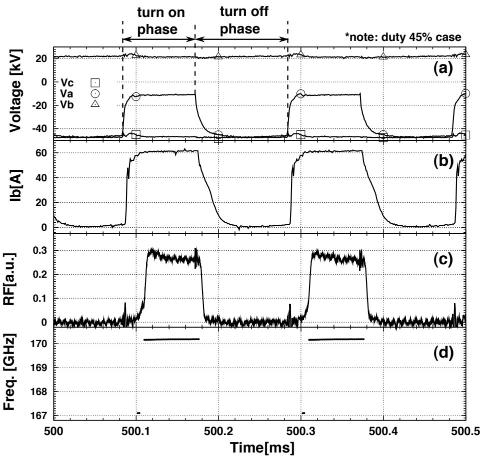

Fig. 2 Typical waveform of 5kHz modulation with anode switch.

Typical waveform of 5kHz modulation experiments with the anode switch is shown in Fig. 2. The anode voltage (V_a) is shaped as rectangular 5kHz waveform with the anode switch turning on and off (see Fig.2(a)). The switch successfully shorts between the anode and the cathode within ~45μs. The perturbation of the cathode voltage V_c and the body voltage V_b due to the rectangular modulation of the V_a is acceptable. The ramp up speed of the V_a is about ~20μs. The beam current I_b follows the V_a as shown in Fig.2(b). The I_b goes to zero when the V_a equals to the V_c as expected. Figure 2(c) shows the RF waveform measured by a diode detector and Figure 2(d) shows a time domain frequency measurement. After the careful adjustment of the parameters for high power operation, the output power of 1.1MW/60s was achieved with total electrical efficiency of 48%. There was no restriction about the pulse length, so it could be extended if required.

3. A dual frequency gyrotron

A high power dual frequency gyrotron is designed and tested. The design is based on 170GHz single frequency gyrotron with a triode MIG[2]. The triode MIG enables to choose variety of oscillation modes for different frequencies with suitable pitch factor, which is the advantage for the dual frequency gyrotron. Another frequency of 137GHz is selected in order to use 1.853mm thickness single disk output window. Cavity modes are $TE_{31,11}$ and $TE_{25,9}$ for 170GHz and 137GHz operation, respectively, which have high mode conversion efficiency to the RF beam mode with similar radiation angles.

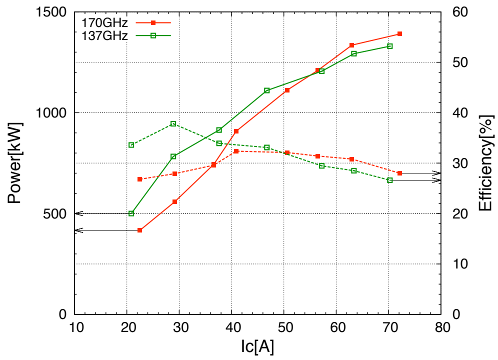

Fig. 3 Power and efficiency without a depressed collector as a function of the beam current.

The power and the oscillation efficiency measured with repetitive 0.5ms short pulse shots are shown in Fig.3. More than 30% efficiency without depressed collector for the beam current of 40-50A is achieved. The maximum power of 1.39MW for 170GHz operation and 1.33MW for 137GHz operation are obtained with beam current of 72A and 70A, respectively. The measured frequencies at 30ms are 170.2GHz for 170GHz operation and 137.1GHz for 137GHz operation. Up to now, in the long pulse experiments, 1MW/5sec and 760kW/60sec for 170GHz operation are achieved. The pulse length will be extended and 137GHz long pulse experiments will be conducted in near future.

4. Summary

The recent progress of the gyrotron development for ITER is introduced. A 5kHz modulation by using the anode switch is demonstrated and the 1.1MW/60s is achieved (up to now). This is the first 5kHz modulation experiment with full current suppression for high power with long pulse. A dual frequency gyrotron (170/137GHz) with the triode MIG is successfully designed and tested. The high efficiency operations for both frequencies are demonstrated.

References

[1] J. How and R. Reichle, Eds., *ITER 2009 Baseline: Plant Description (PD)*.

[2] K. Sakamoto, A. Kasugai, K. Takahashi, R. Minami, N. Kobayashi, and K. Kajiwara, *Nat. Phys.*, **3** (2007) 411.