High Power and Long Pulse Experiments of ITER Gyrotron
ITER用ジャイロトロンにおける高出力・長パルス実験

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At JAEA, two types of gyrotrons, which $TE_{31,11}$ mode and $TE_{31,9}$ mode are oscillated are under development for ITER EC system. $TE_{31,11}$ mode gyrotron has property of multi-frequency oscillation such as 170 GHz, 137 GHz and 104 GHz. These maximum output power achieved 1.19 MW for 170 GHz, 1.01 MW for 137 GHz and 1.04 MW for 104 GHz. In 40 m transmission experiment, HE_{11} mode purity of ~ 93 % and power transmission efficiency of ~ 94 % were obtained for each frequency. In $TE_{31,9}$ mode gyrotron experiments, 1 MW with output efficiency of 33 % was realized in 1 ms operation without depressed collector voltage. And, 0.61 MW with total electric efficiency of 51 % was achieved in 10 s operation with depressed collector voltage.

1. Introduction

A 20 MW electron cyclotron heating and current drive (EC H&CD) system is planned in ITER. This system is composed of 24 gyrotron systems including superconducting magnet s and matching optics unit s (MOU), high voltage power supplies, 125 m transmission lines, 4 upper port launchers and an equatorial port launcher [1,2]. Japan Domestic Agency (JADA) procures 8 gyrotrons and the equatorial port launcher. The required specifications of a gyrotron are 170 GHz oscillation frequency, continuous wave operation with > 1 MW output power and total electrical efficiency of > 50 %. And, 5 kHz high–speed power modulation is required to synchronously inject EC waves into magnetic islands rotating generated by neo-classical tearing mode. In addition, to avoid generation of unnecessary stray RF in launcher ports, HE_{11} mode purity at the MOU exit demands > 95 %.

$TE_{31,8}$ mode gyrotron with a triode magnetron injection gun was developed at JAEA. The output power, the electric efficiency and the pulse width achieved 1 MW / 55 % / 800 s [3]. The demand performance was almost filled by these results. Moreover, 5 kHz full power modulation was demonstrated by an electron beam modulation using an anode voltage switching [4]. However, the output power of 1 MW was marginal because of high heat load in the cavity resonator. To avoid the heat load at the cavity resonator and obtain more than 1 MW enough, development of gyrotrons with high-order mode was started. We are developing two types of gyrotrons which $TE_{31,11}$ mode and $TE_{31,9}$ mode are oscillated.

2. $TE_{31,11}$ mode gyrotron

A cavity radius in $TE_{31,11}$ mode gyrotron is 20.87 mm and the cavity wall loading becomes considerably low (1.4 kW/cm^2). Therefore, high power operation of 1.5 MW is expected. Moreover, $TE_{31,11}$ mode gyrotron has advantage for multi-frequency oscillation [5]. RF beam with frequency such as 104 GHz ($TE_{19,7}$) and 137 GHz ($TE_{25,9}$) including 170 GHz ($TE_{31,11}$) is radiated to

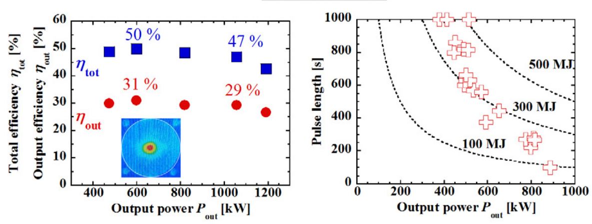


Fig.1. Total and output efficiencies dependence of output power and achieved pulse length in steady stated operation for 170 GHz.

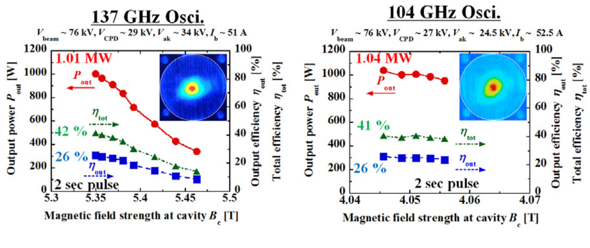
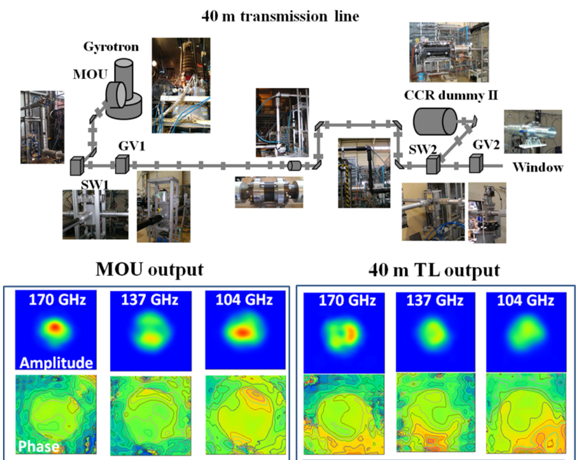


Fig.2. Magnetic field dependence of output power for 137 GHz and 104 GHz in 2 sec pulse operation with depressed collector.

same direction. Therefore, these beams pass through a diamond disk window without reflecting and transmit toward the MOU without moving a final mirror in the gyrotron. At 1 MW operation, output power and total electrical efficiency of 1.05 MW (47 %) for 170 GHz, 1.01 MW (42 %) for 137 GHz and 1.04 MW (41 %) for 104 GHz were obtained as shown in Fig.1 and 2. At present, achieved maximum power for 170 GHz oscillation was 1.2 MW. The pulse duration was extended up to 1000 sec at 0.51 MW for 170 GHz.

We performed 40 m transmission experiments for each frequency as shown in Fig.3. HE_{11} mode purity at the MOU exit estimated from radiation patterns measured by an infrared camera were 94.4 % for 170 GHz, 92.6 % for 137 GHz and 92.7 % for 104 GHz. Moreover, these values at the end of 40 m transmission line including 7 miter bend were 93 % for 170 GHz, 92.5 % for 137 GHz and 94 % for 104 GHz. The power transmission efficiency reached 93.8 % for 170 GHz, 95.1 % for 137 GHz and 93.7 % for 104 GHz.



	170 GHz	137 GHz	104 GHz
HE_{11}	94.4 %	92.6 %	92.7 %
LP_{02}	1.3 %	2.3 %	0.5 %
$LP_{11,odd}$	0.5 %	1.2 %	1.1 %
$LP_{11,even}$	0.1 %	0.2 %	0.7 %

	170 GHz	137 GHz	104 GHz
HE_{11}	93.1 %	92.5 %	94.0 %
LP_{02}	1.1 %	0.9 %	0.9 %
$LP_{11,odd}$	0.6 %	0.9 %	0.9 %
$LP_{11,even}$	1.3 %	0.3 %	0.3 %

Power measurement with 20 sec operation	170 GHz	137 GHz	104 GHz
Power at gyrotron window	430 kW	328 kW	264 kW
Power at CCR Dummy load II	390 kW	294 kW	223 kW
Transmission efficiency at Long TL	93.8 %	95.1 %	93.7 %

Fig.3. Schematic view of 40 m transmission line, HE_{11} mode contents at MOU exit and the end of 40 m TL, and power transmission efficiencies for 170 GHz, 137 GHz and 104 GHz.

3. $TE_{31,9}$ mode gyrotron

The effect of mode competition in $TE_{31,9}$ mode gyrotron is small compared with $TE_{31,11}$ mode gyrotron. Therefore, high efficiency operation of >

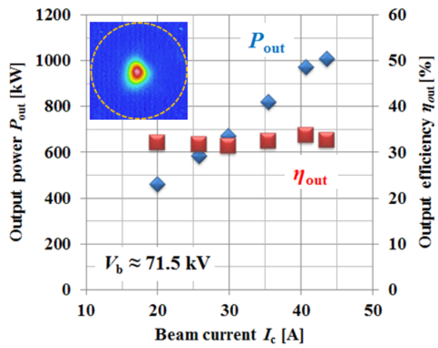


Fig.4. Beam current dependence of output power and output efficiency in short pulse experiment (< 1ms) for $TE_{31,9}$ mode gyrotron.

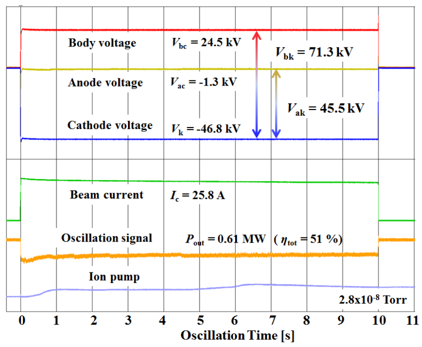


Fig.5. Time evolution of 0.61 MW oscillation with total efficiency of 51 %.

50 % in hard-self excitation region is expected. Of course, this gyrotron has a margin for heat load at the cavity resonator and enables CW operation of 1.2 MW. Figure 4 shows the beam current dependence of output power and output efficiency without depressed collector at 1 ms short pulse operation. The efficiency exceeds 30 %. 1 MW output power was obtained at $I_c \sim 43.6$ A and the efficiency is 32.6 %. After short pulse operation, we started long pulse operation with depressed collector. Figure 5 shows 10 sec operation with 0.61 MW output power. The output efficiency reached 33.4 % and the electrical total efficiency of 51 % was obtained. 1 MW with more than 50 % and steady state operation will be tried.

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