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複数周波数大電力ジャイロトロン開発の進展

Progress in Development of Multi-Frequency High-Power Gyrotron

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Summary

I. 1.0 MW steady state operation has been achieved for ITER, and over-1MW of 1.2MW with ~ 50 % have been demonstrated.
II. Quad-frequency oscillations (0.9MW/5s/104GHz, 1MW/6s/137GHz, 1MW/300s/170GHz, 0.4MW/5s/203GHz) have been demonstrated.
III. 236 GHz ($TE_{43,15}$) for DEMO can be expected up to 0.9 MW output power even if the ITER gyrotron. Over-1 MW will be expected by exciting $TE_{49,17}$ mode.

ITER gyrotron at QST

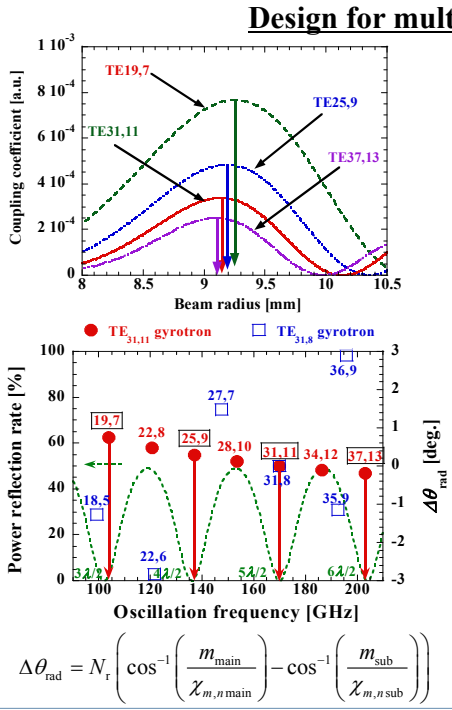
- ITER gyrotron of $TE_{31,8}$ mode had already achieved 1.0 MW CW operation with total efficiency of 55%.
- Higher order mode of $TE_{31,11}$ has been selected to enhance the output power and to realize multi-frequency oscillations.

Design parameters of JA ITER gyrotron

Mode	$TE_{31,8}$	$TE_{31,11}$
Cavity radius	R_c = 17.90 mm	20.87 mm
Triode MIG	R_e = 46.5 mm	Same
Beam radius	R_b = 9.13 mm	Same
Diamond window	D_w = 82 mm t_w = 1.853 mm	Same
Remark	1MW/55%/800s 0.8MW/57%/1hr	Up to 1.4 MW Multi-frequency

◆JA ITER gyrotron is capable of multi-frequency oscillations with uniform directional beam.

Design for multi-frequency oscillation by ITER type gyrotron



$$\Delta\theta_{rad} = N_r\left(\cos^{-1}\left(\frac{m_{main}}{\chi_{m,n\,main}}\right) - \cos^{-1}\left(\frac{m_{sub}}{\chi_{m,n\,sub}}\right)\right)$$

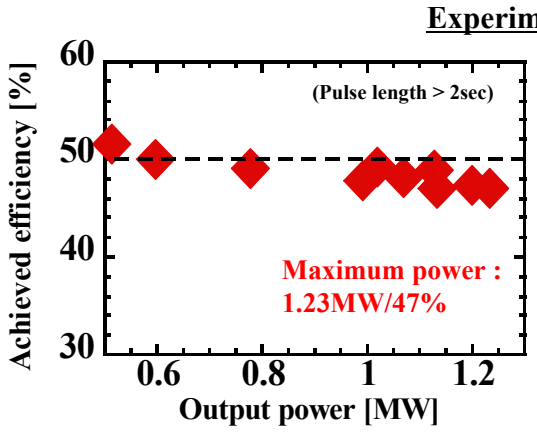
Oscillation frequency	104GHz	137GHz	170 GHz	203 GHz
Cavity Field	4.08 T	5.32 T	6.63 T	7.98 T
Gun Field	0.172 T	0.21 T	0.28 T	0.31 T
Beam radius	9.25 mm	9.19 mm	9.13 mm	9.10 mm
Anode-cathode voltage	28 kV	36k V	42 kV	50 kV
Pitch factor	1.32	1.35	1.35	1.35
Oscillation power	1.12 MW	1.26 MW	1.3 MW	1.3 MW
Oscillation efficiency	39%	44%	45%	45%

(Beam voltage: 72kV and beam current : 40 A)

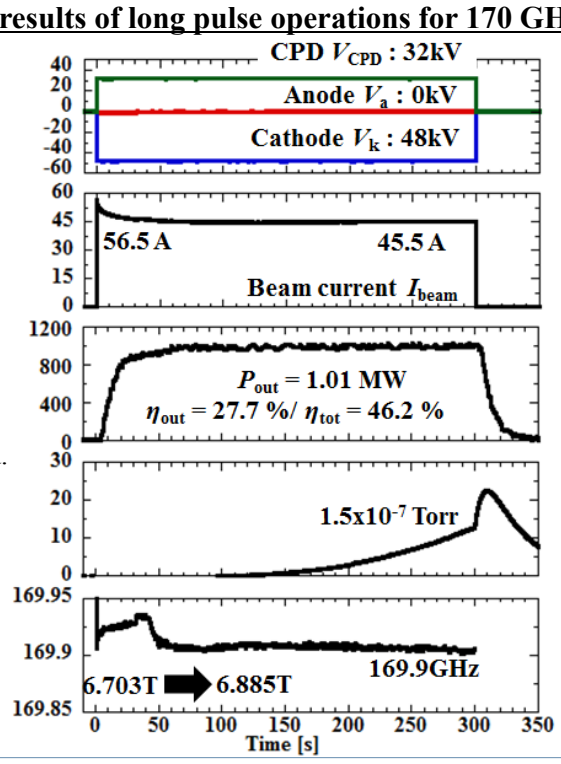
Oscillation frequency (Cavity mode number)	Transmission efficiency between radiator to window
104GHz (TE19,7)	95.5%
137GHz (TE25,9)	96.9%
170 GHz (TE31,11)	98.5%
203 GHz (TE37,13)	97.6%

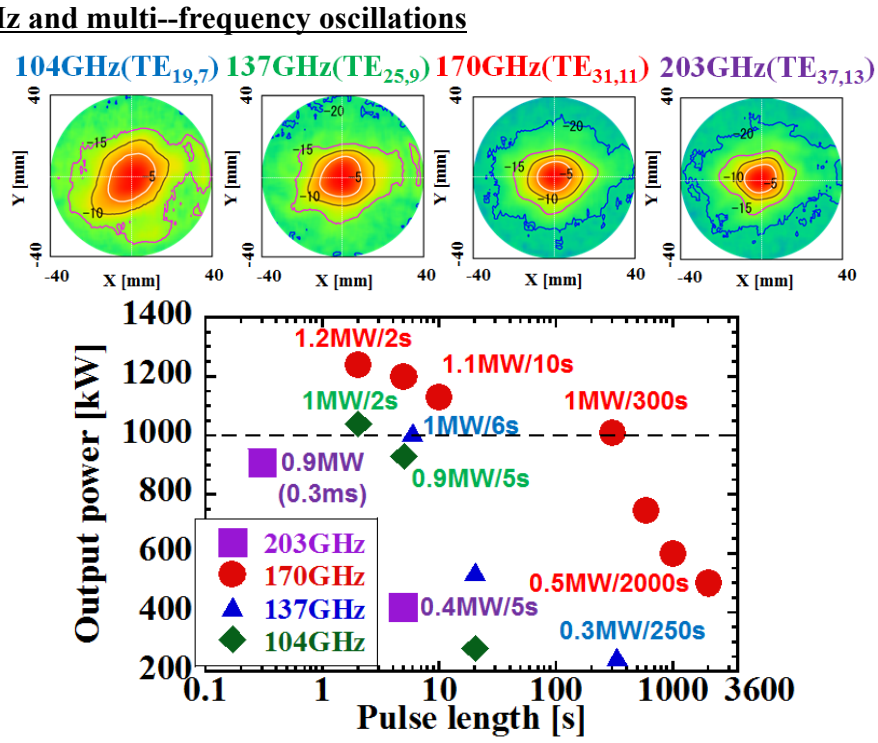
(Radiator design was optimized for170 GHz beam.)

Experimental results of long pulse operations for 170 GHz and multi--frequency oscillations



◆1.2MW power and ~ 50% efficiency have been demonstrated.
◆Steady-state operation at 1MW was achieved (All coolant temperature was saturated).
◆ 1MW-level oscillations of 104 GHz for 5s and 137 GHz for 6s were obtained.
◆ 203GHz oscillation has been demonstrated.
Long pulse operation : 0.4 MW for 5s (The world's first)
Achieved maximum power : 0.9 MW/0.3ms





Power balance in gyrotron for quad-frequency oscillations

	104 GHz	137 GHz	170 GHz	203 GHz
DCB [%]	6.1	3.9	2.3	2.6
Relief window [%]	2.3	1.4	0.8	0.9
viewing ports [%]	0.6	0.3	0.1	0.1
Diffraction loss [%]	8.9	5.6	3.3	3.7
Mirrors [%]	0.9	0.7	0.7	0.6
Radiator [%]	2.0	1.8	1.8	1.7
Cavity [%]	2.8	3.0	3.4	3.8
Ohmic loss [%]	5.7	5.4	5.8	6.1
Total internal loss [%]	14.6	11.1	9.1	9.7
Output eff. [%]	24.0	26.5	28.0	25.0
Cavity eff. [%]	27.5	29.4	30.5	27.4

x3 x2

DCB absorber

Relief window load

◆ Oscillation efficiencies at the cavity for sub-frequencies were close to one at main designed 170GHz oscillation.
◆ Low frequency oscillations are limited due to water temperature at RF absorber.
◆ Modification of the radiator design is underway to realize longer pulse 1MW operation (> 30s) at 104 GHz and to apply the low field experiments (1.8 T) in ITER.

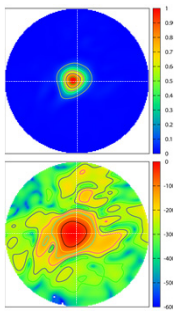
Beam profile at radiator

◆Target efficiencies is > 98 % at both frequencies.
◆Improvement of 2 % is achieved at 104 GHz.
◆The efficiency at 170 GHz is comparable.

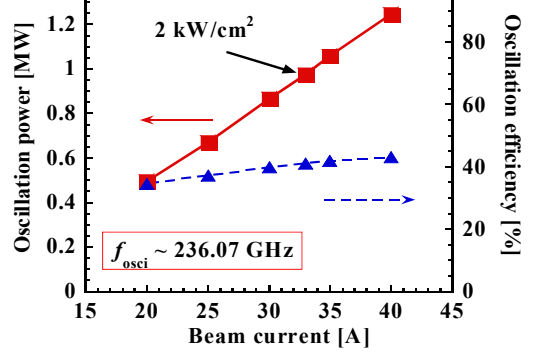
Possibility of 236 GHz oscillation for demo-reactor generation

Case 1 : ITER type gyrotron

$TE_{43,15}$ mode



V_{beam} = 72 kV, α = 1.2, B_c ~ 9.29 T



◆Calculated transmission efficiency from radiator to window is 96.6 %.
◆Cavity heat load reaches 2kW/cm² at 1 MW cavity power.
◆If the internal loss is ~10 % (203GHz), output power is up to 0.9 MW.

Case 2 : Modified gyrotron

$TE_{49,17}$ mode

Cavity radius:
23.80 mm
Beam radius:
10.31 mm
Window thickness :
2.14mm

V_{beam} = 72 kV, α = 1.2, B_c ~ 9.28 T

◆If higher order mode $TE_{49,17}$ mode in same mode-group is selected for 236 GHz oscillation, the oscillation power increases up to 1.35 MW (Output power ~ 1.2 MW).
◆Multi-frequency oscillation (178GHz/207GHz/265GHz) is expected.