COMPLETION OF MANUFACTURING AND TESTING OF 8 ITER GYROTRONS WITH ITS AUXILIARY SYSTEMS

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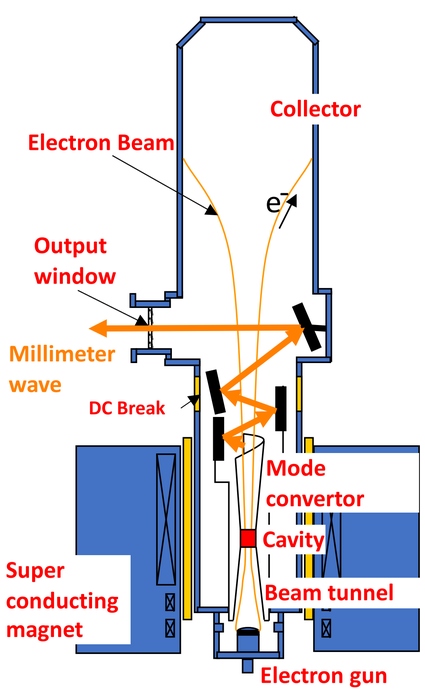
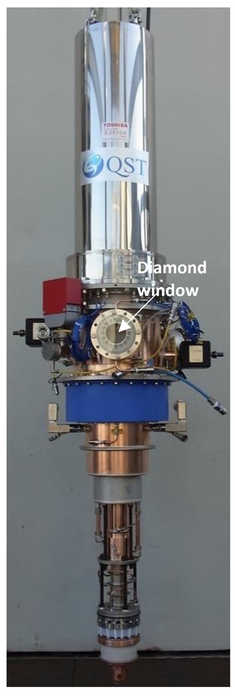
INTRODUCTION

QST has been developed collaborating with Toshiba (now a day Canon Electron Tube and Devices) the gyrotron for ITER since 1991. The first depressed collector gyrotron is developed in 1994 which increases the electrical efficiency from 30% to 50%. In 1997, the first diamond window gyrotron is developed with cooperation with FZK in Germany. After these major breakthroughs, the remaining issue is the internal heating by stray RF inside the gyrotron. It is also overcome by adopting the ceramic beam tunnel and dimpled wall mode convertor.

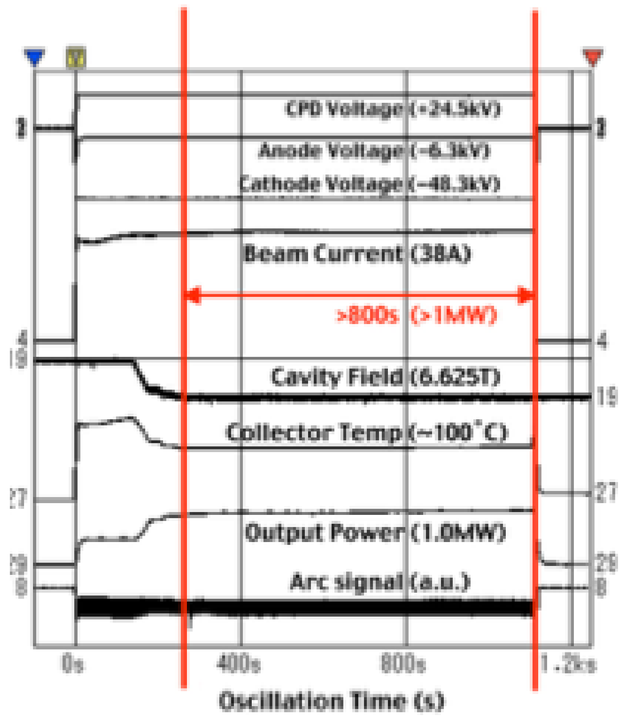




General Feature of QST gyrotron

- ✓ Depressed collector (DC break just under the window)
- ✓ Triode electron gun for adjusting the pitch factor separately to the beam diameter at cavity.
- ✓ Ceramic Beam tunnel.
- ✓ Dimpled wall mode convertor.
- ✓ Large bore SCM for mechanically adjusting the position of the SCM to align the cavity axis.

$TE_{31,8}$ ITER PROTOTYPE GYROTRON



First successfully developed long pulse gyrotron.

- ✓ Cavity mode is $TE_{31,8}$
- ✓ Oscillation efficiency : 36.5%
- ✓ Electrical efficiency: 55%
- ✓ Maximum allowable output power is 1MW, which is limited by the heat load on the cavity.

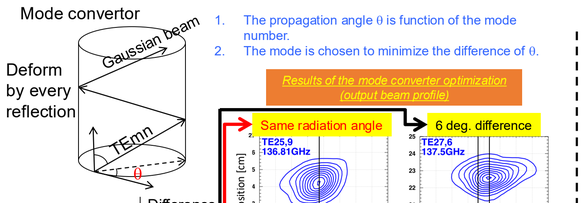
The cavity is damaged during the 1MW operation campaign.

Large cavity is necessary for stable 1MW operation

MULTI FREQUECY GYROTRON DEVELOPMENT

During the process of the mode selection for large cavity, a mode convertor, which can work for different frequency is discovered. The radiation angle from the mode convertor depends on the mode number which corresponding to the frequency, therefore, in natural, the mode convertor work for single frequency. However, it is discovered some discrete mode numbers have identical radiation angle, which allows to develop the mode convertor working for different frequency. As a result, the multi frequency gyrotron development is rapidly progressed. The 170GHz, 137GHz and 104GHz long pulse high power operation is realized.

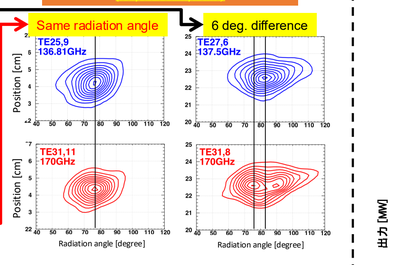
Mode convertor

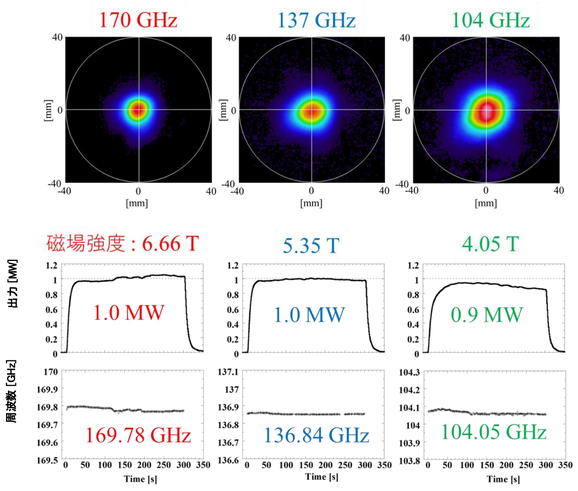


1. The propagation angle θ is function of the mode number.
2. The mode is chosen to minimize the difference of θ.

Mode candidate		Difference of θ
TE31,8	TE27,6	4.2°
TE31,8	TE26,6	3.3°
TE31,12	TE24,10	1.1°
TE31,10	TE28,7	6.5°
TE31,11	TE25,9	0.05°

Results of the mode converter optimization (output beam profile)

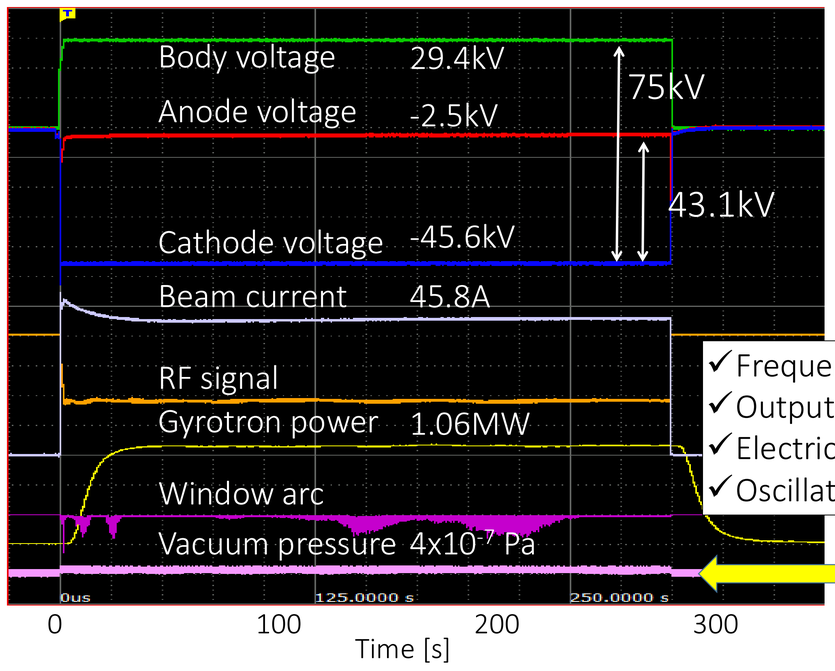




時間 [s]	時間 [s]		時間 [s]
発振周波数	170 GHz	137 GHz	104 GHz
ジャイロトロン出力	1.0 MW	1.0 MW	0.9 MW
連続動作時間	300秒	300秒	300秒

$TE_{31,11}$ ITER GYROTRON

By applying the large cavity, the cavity mode is increased from $TE_{31,8}$ to $TE_{31,11}$. As a result the maximum allowable output power is increased from 1 MW to 1.2 MW due to large cooling area at cavity. However, higher cavity mode has large amount of the competing mode. Because of that the electrical efficiency is decreased from 55% to 45%. In order to avoid competing mode, the electron beam radius at cavity is adjusted by time. After this invention, the electrical efficiency recovered from 45% to 50% which satisfies requirement of ITER gyrotron.



- Stable 300sec pulse is developed for factory acceptance test for ITER.

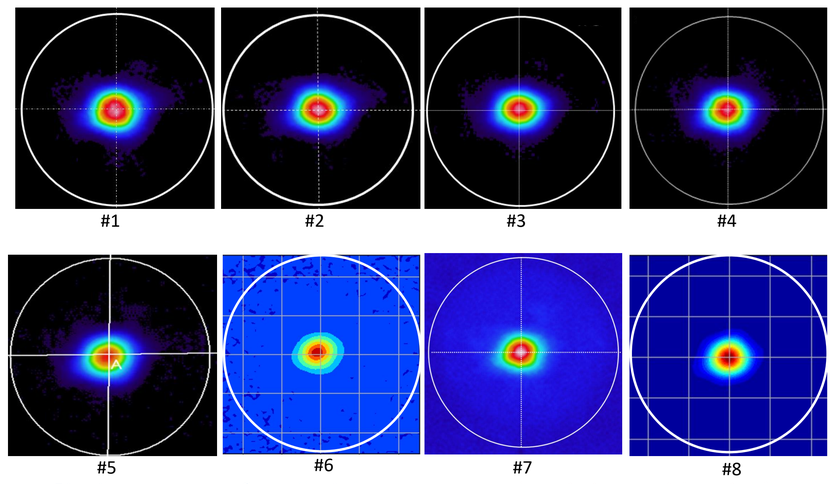
✓Frequency :169.85GHz
✓Output power :1.06MW
✓Electrical efficiency :51%
✓Oscillation efficiency :31 %

Low pressure

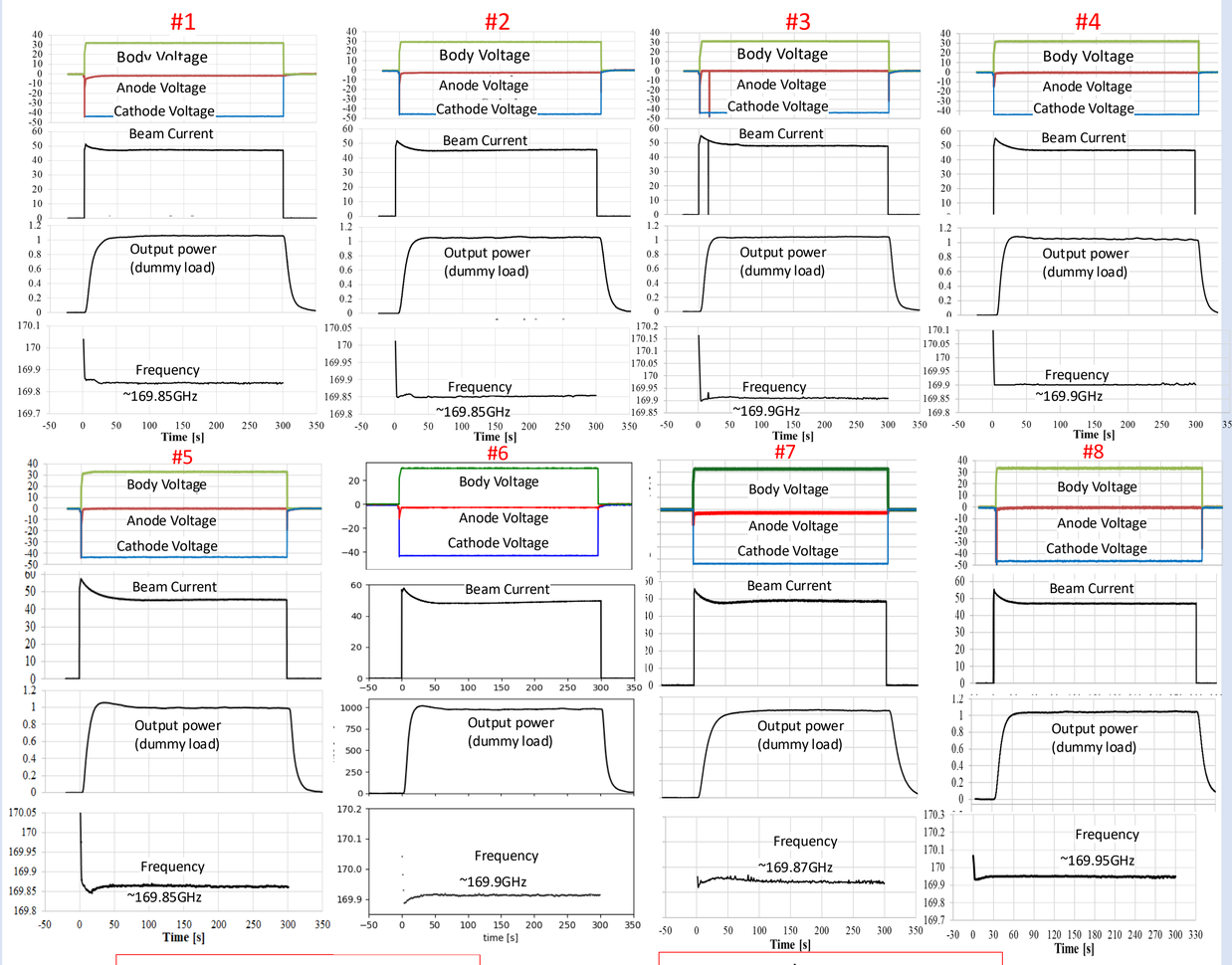
8 GYROTRON OPERATION RESULT

After the last FEC conference in 2023, all 8 gyrotron conditioning and testing in QST is completed. Despite the identical design and manufacturing process, the output powers of each gyrotrons are not identical. The reason is not clear, but the optimized parameters are not identical for all gyrotrons, which may cause the scattering of the gyrotron power ±35kW among 8 gyrotrons. These results with history of the gyrotron development in QST is reported.

- Window flange RF pattern (Short pulse)



Similar pattern for all eight gyrotrons, but it is not identical



Voltage ± 1.6kV

Power ± 25kW

Beam current ± 1.1A

Frequency ± ~25MHz

SUMMARY AND CURRENTS STATUS

As a result of the continues work for the gyrotron since 1991, QST successfully developed the ITER gyrotron, which satisfy the 1MW stable operation with 50% electrical efficiency. All 8 gyrotrons are already delivered to ITER site and the first gyrotron is installed as a first plasma heating device at ITER site. In parallel, as a side work of the ITER gyrotron development, the multi frequency gyrotron is successfully developed.