New Developments in Russia of Gyrotrons for Plasma Fusion Installations

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ABSTRACT

- Russian 170 GHz gyrotrons for ITER
- Gycom/IAP deliveries of MW gyrotrons in last years
- New approaches in development of MW gyrotrons

INTRODUCTION

Electron cyclotron systems of fusion installations are based on powerful millimetre wave sources – gyrotrons, which are capable to produce now megawatt microwave power in very long pulses. Gyrotrons for plasma fusion installations usually operate at frequencies 40-170 GHz. Requested output power of the tubes is about 1 MW and pulse duration is between seconds and thousands seconds (depending on plasma machine parameters). To provide operation with indicated parameters the gyrotrons have very large transverse cavity sizes, output barrier windows made of CVD diamond discs, electron beam collectors apply effective energy recovery. The main partners in the development of gyrotrons in Russia are the Institute of Applied Physics and industrial company GYCOM Ltd.

The most developed gyrotrons are now the tubes for ITER which demonstrate parameters corresponding to ITER requirements. High-level parameters were also achieved with long-pulse 140 GHz gyrotrons developed for EAST and KSTAR installations. Some steps were done in development of higher frequency (230-700 GHz) gyrotrons for future plasma installations and for plasma diagnostics. Novel ideas were proposed to enhance gyrotron operation.

170 GHz gyrotron for ITER

In ITER installation there will be 24 gyrotron systems with 1 MW power each. Russian contribution consists of 8 gyrotron systems. ITER requirements include also high efficiency of the gyrotrons over 50%, possibility of power modulation with frequency up to 5 kHz, compatibility of the gyrotron complex with ITER control system. Development of the gyrotron system for ITER is based on solution of many very difficult scientific and engineering problems.

In May, 2015 a Russian Prototype of ITER Gyrotron System was completed and its operation was demonstrated. In 2016-2020 four serial gyrotron systems were fabricated. Two more systems are in manufacturing.

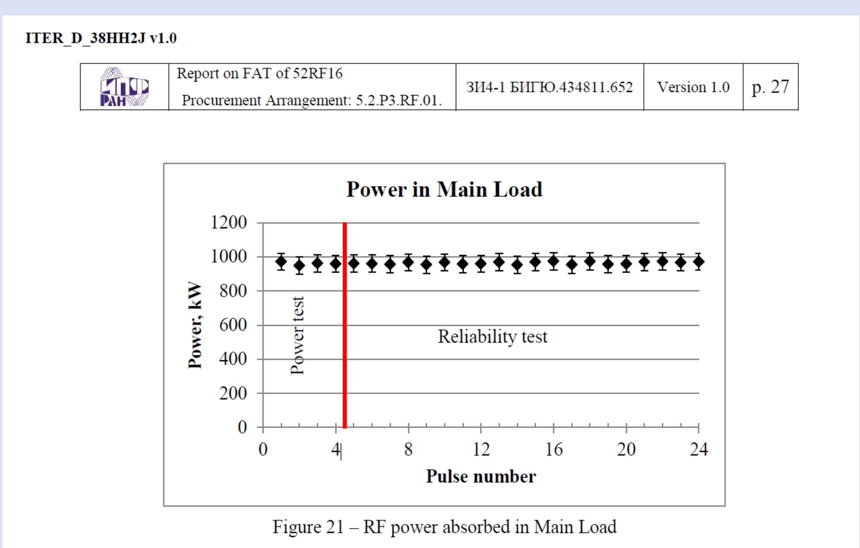
All these four ITER gyrotron systems showed reliable operation in 1000 second pulses at megawatt power and efficiency higher than 50% (list 1 and table 1). The gyrotron output wave beam fed with low losses the corrugated HE11 waveguide of 50 mm diameter. The measured X-rays radiation and stray microwave radiation do not exceed safety levels.

List 1: Hyperlinks and IDM numbers for factory acceptance test protocols

1- RF power source [FAT report of 1-st delivery RF DA RF Power Source (VJLBHF v1.1)](#) IDM: VJLBHF
2- RF power source [FAT Report 2-nd gyrotron set 1-st phase (X25VPP v1.0)](#) IDM: X25VPP
3- RF power source [FAT report 3-rd gyrotron set 1-st phase (289M54 v1.0)](#) IDM: 289M54
4- RF power source [FAT report 4-th gyrotron set (38HH2J v1.0)](#) IDM: 38HH2J

Table 1. Some figures from the gyrotron system FAT protocols

#	date	Frequency (170+/-0.3) GHz	Power in HE11 waveguide (req. > 0.96 MW)	Cathode Voltage/Current Tube Efficiency (req. > 50%)	Other requirements (water, X-rays, RF leakage, modulation, …)
1	13.10.2017	169.9 GHz	0.96 MW	42.5 kV / 42 A 55%	OK
2	22.08.2018	169.9 GHz	0.96 MW	44 kV / 42.4 A 53%	OK
3	04.10.2019	169.9 GHz	0.97 MW	43.7 kV / 40 A 57%	OK
4	12.06.2020	169.84 GHz	0.97 MW	42.5 kV / 42.8 A 55%	OK



20 pulses at 1 MW power, duration 500 s, and duty cycle ¼. Reliability 100%.

Photo of the gyrotron system parts

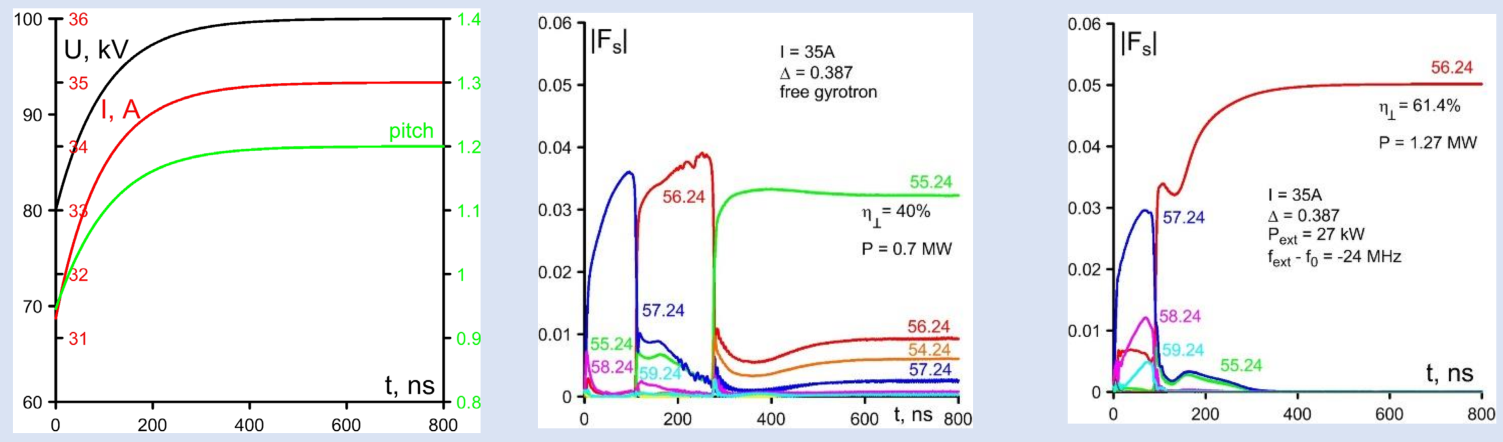
GYCOM/IAP deliveries of MW gyrotrons in last years

More than thirty MW gyrotrons in last 10 years

New approaches in development of MW gyrotrons

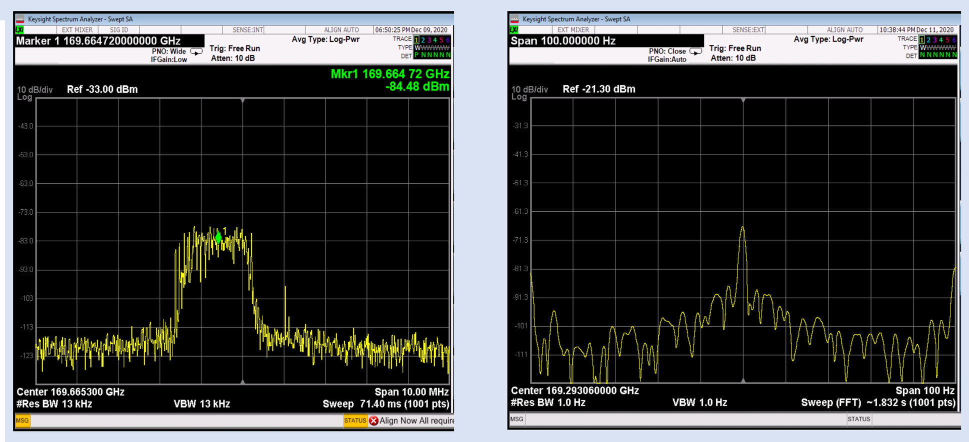
Simulations also show that using the gyrotron frequency stabilization and oscillator phase locking helps to provide stable gyrotron operation at very high modes (as $TE_{56.24}$), at very high frequencies (as 345 GHz) with megawatt power are encouraging. High frequencies are required for future plasma machines with high magnetic fields.

Figures below - Switching-on of 345 GHz gyrotron: a-electron beam parameters, b – free running gyrotron (no input signal); c - 27 kW external signal provides the single mode gyrotron operation with significantly higher power and efficiency.



a b c

CW gyrotron-driver for the frequency locking of megawatt power gyrotron was tested. The width of its spectrum is about 1 Hz at 170 GHz frequency. The relative stability $\Delta f / f = 6 * 10^{-12}$ at output power of 10 kW - record power for systems with high stability.



without stabilization with stabilization

CONCLUSION

- Four 170 GHz gyrotron systems for ITER were fabricated. All the passed successfully the factory acceptance tests.
- More than thirty megawatt gyrotrons with CVD diamond windows were supplied to different plasma machines for last ten years.
- Experiment of frequency locking of megawatt power 170 GHz gyrotron is planned for 2021.

REFERENCES

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