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Design and Experimental Test Of 250 GHz/300 kW/CW Gyrotron

G. Denisov[1,2], A. Fokin[1], M. Glyavin[1], A. Kuftin[1], M. Morozkin[1], V. Malygin[1], M. Proyavin[1], A. Sedov[1], E.Soluyanova[1,2], E. Sokolov[1,2], A. Tsvetkov[1], E. Tai[1,2], V. Zapevalov[1]

[1]Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russia, ap.fokin@mail.ru
[2]GYCOM Ltd., Nizhny Novgorod, Russia

One of the most important applications of modern gyrotrons is the plasma heating and control of the current in controlled thermonuclear fusion facilities. 170-GHz 1MW-power continuous regime gyrotrons with efficiency about 50% is developed for the ITER project in several countries, including Russia. Now ITER is under intensive construction. The concept of DEMO fusion power plant includes the upgrade of the heating and current drive systems. The main points are the increase of heating frequency up to 230 GHz and higher and increase in the total microwave power up to 50 MW [1]. In order to satisfy new conditions it is important to solve many scientific and engineering problems, and high-frequency high-power gyrotrons are now undergoing development in many groups [2, 3]. Here we present the design and experimental results of a 250 GHz continuous-wave (CW) gyrotron developed jointly by IAP RAS and GYCOM Ltd.

Gyrotron design

The main limiting factor for the design of the gyrotron is the hot bore diameter of available cryomagnet. For cryogen-free magnet JMTD-10T100 (JASTEC Inc., Japan) the 100 mm hot bore limited the size of an electron-optical system and quasi-optical converter. As a result, the $TE_{19,8}$ mode was chosen as the operating one with a cavity radius of 9.34 mm. The cavity length was determined by maximum thermal loading on the cavity wall, which for ideal copper cannot exceed 1.5 kW/cm^2. Based on the numerical simulation of the electron-wave interaction efficiency, the cavity length was set as 10 mm with nominal beam current for CW regime 12.5 A. The electron beam is formed by a diode-type magnetron injection gun, and recuperation of residual electron energy is performed by depress collector. The total accelerating voltage U_0 = 55 kV, with negative cathode potential, grounded collector and body voltage of 20 kV. The possibility of stable single-mode oscillation of the operating mode was demonstrated by numerical modeling in self-consistent model with efficiency up to 40%.

The tube is equipped with Denisov-type quasi-optical converter, which provides the transformation of the operating mode to the Gaussian beam and separation of wave and electron beams. It consists of shaped waveguide, parabola, four guiding mirrors and synthesized mirror for direction of the wave beam in the output window. For initial production and short pulse tests of the tube the simple boron nitride (BN) window with diameter of 66 mm was used. Its thickness was optimized to minimize the reflections at an operating frequency 250 GHz. The future CW tests of the gyrotron assume the replacement of the BN window by a CVD diamond window.

Operating frequency	250 GHz
Operating mode	$TE_{19,8}$
Accelerating voltage, U_0	55 kV
Body voltage	20 kV
Beam current (CW)	12.5 A
Cavity radius	9.34 mm
Cavity length	10 mm
Beam radius	3.93 mm

Fig. 1. The general view of the 250 GHz gyrotron installed in the cryomagnet

Experimental test

The experimental investigation of the produces tube were performed in a pulse-periodic regime, with pulse duration of 40 μs and repetition rate of 10 Hz. The first tests were performed without electron energy recuperation, using pulsed power supply developed and manufactured in IAP RAS. In experiments, the used accelerating voltage was up to 60 kV with beam currents up to 20 A. Also, an additional coil was installed in the cathode region of the tube for fine tuning of the magnetic field on the cathode.

The measurement system included NorthStar PVM-5 high voltage probe for measurement of the accelerating voltage, Rogowski coil with sensitivity of 50 mV/A for measurement of beam current and a water calorimetric dummy load for power measurements. The output power was calculated based on measured study-state average power in pulse-periodical regime with taking into account duty cycle. The frequency measurements were performed using resonant-cavity wave meter.

The maximum output power measured in experiment reached 330 kW at the operating frequency 249.74 GHz with total efficiency more than 30% without energy recuperation. The measured dependence of output power and efficiency on the current of the electron beam s presented on the fig.2. For nominal beam parameters of 55 kV and 15.5 A the output power was about 200 kW, which is well corresponding with theoretical estimations on the design stage.

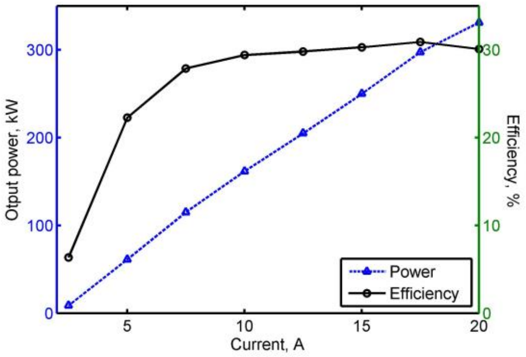

Fig. 2. Dependence of output power and efficiency on beam current

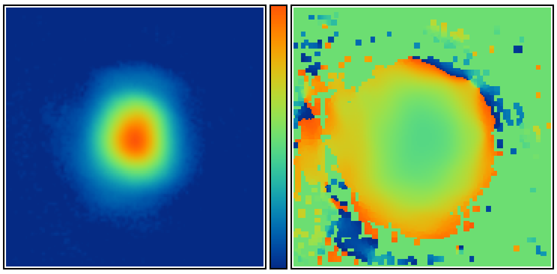

Fig. 3. Measured amplitude and reconstructed phase of the beam

The measurements of microwave beam distribution were performed using the infrared camera technique [4] and presented in fig.3. Resulting content of the Gaussian beam exceeds 98%.

The gyrotron was successfully used for initiation of localized gas discharge. The main result of such experiments is detection of plasma emission in the EUV spectral ranges of 13-17 nm (for xenon) and 18-50 nm (for xenon and argon) [5].

Conclusion

The 250 GHz gyrotron has been developed, manufactured and experimentally tested. The microwave power up to 330 kW with 30% efficiency without collector depression was obtained in 40 µs pulses.

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References

1. *G.Granucci et al.* The EC-system of EU DEMO: concepts for a reactor heating system // EPJ Web of Conferences 149, 03003 (2017).
2. *R.Ikeda et al.* Development of multi-frequency gyrotron for ITER and DEMO at QST // 41st International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz 2016) Copenhagen, Denmark.
3. *J.Jelonnek et al.* Design considerations for future DEMO gyrotrons: A review on related gyrotron activities within EUROfusion // Fusion Engineering and Design, 123, 241-246 (2017).
4. *S.O.Kuznetsov, V.I.Malygin.* Determination of gyrotron wavebeam parameters // Int. J. of Infrared and Millimeter Waves, 12, 11, 1241-1252 (1991).
5. *A.G.Shalashov et al* Observation of extreme-ultraviolet light emission from an expanding plasma jet multiply-charged argon or xenon ions // Appl. Phys. Lett. (submitted).