Suppression of Emission Nonuniformity Effect in Gyrotrons

O. Louksha, D. Samsonov, G. Sominski, and S. Syomin

Saint-Petersburg State Polytechnical University (SPbSPU), 29 Polytechnicheskaya st., St. Petersburg 195251, Russia
e-mail: louksha@rphf.spbstu.ru

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INTRODUCTION

The requirement of high performance efficiency of a gyrotron is high quality of a helical electron beam (HEB). One of the important sources of beam quality deterioration is **nonuniform emission** from thermionic cathodes of magnetron-injection guns (MIGs) operating temperature limited. The beam spatial nonuniformities caused by nonuniform emission can lead to the increase of velocity spread and to the excitation of parasitic low-frequency oscillations (LFOs) in the space charge accumulated in the region between the cathode and the magnetic mirror, which prevent to form HEBs with high rotational energy of electrons and therefore to achieve high efficiency of gyrotrons.

Advanced experimental research of cathode emission nonuniformities in gyrotrons was performed at SPbSPU. As a result, the influence of emission nonuniformities on the parasitic LFOs and on the gyrotron efficiency was determined [1], and a method for improvement of cathode emission uniformity was developed and tested [2].

In this paper, we study the influence of the emission nonuniformities on the velocity spread of electrons in HEB and show the possibility to decrease negative effect of these nonuniformities by using a multi-sectional control electrode insulated from the cathode unit. New data on operation of the 74.2 GHz, 100 kW gyrotron with such control electrode are also described in the paper.

[1] O. Louksha, D. Samsonov, G. Sominskii, and S. Semin, “Dynamic processes in helical electron beams in gyrotrons,” *Technical Physics*, vol. 58, pp. 751-759, May 2013.
[2] G. Dammertz, O. Louksha, G. Sominski, and M. Thumm, “On the possibility to use the treatment of gyrotron cathodes by the potassium ion flow for their emission homogeneity increase,” IRMMW-THz 2007, pp. 690-691, Cardiff, UK, Sept. 3-7, 2007.

4-MM GYROTRON

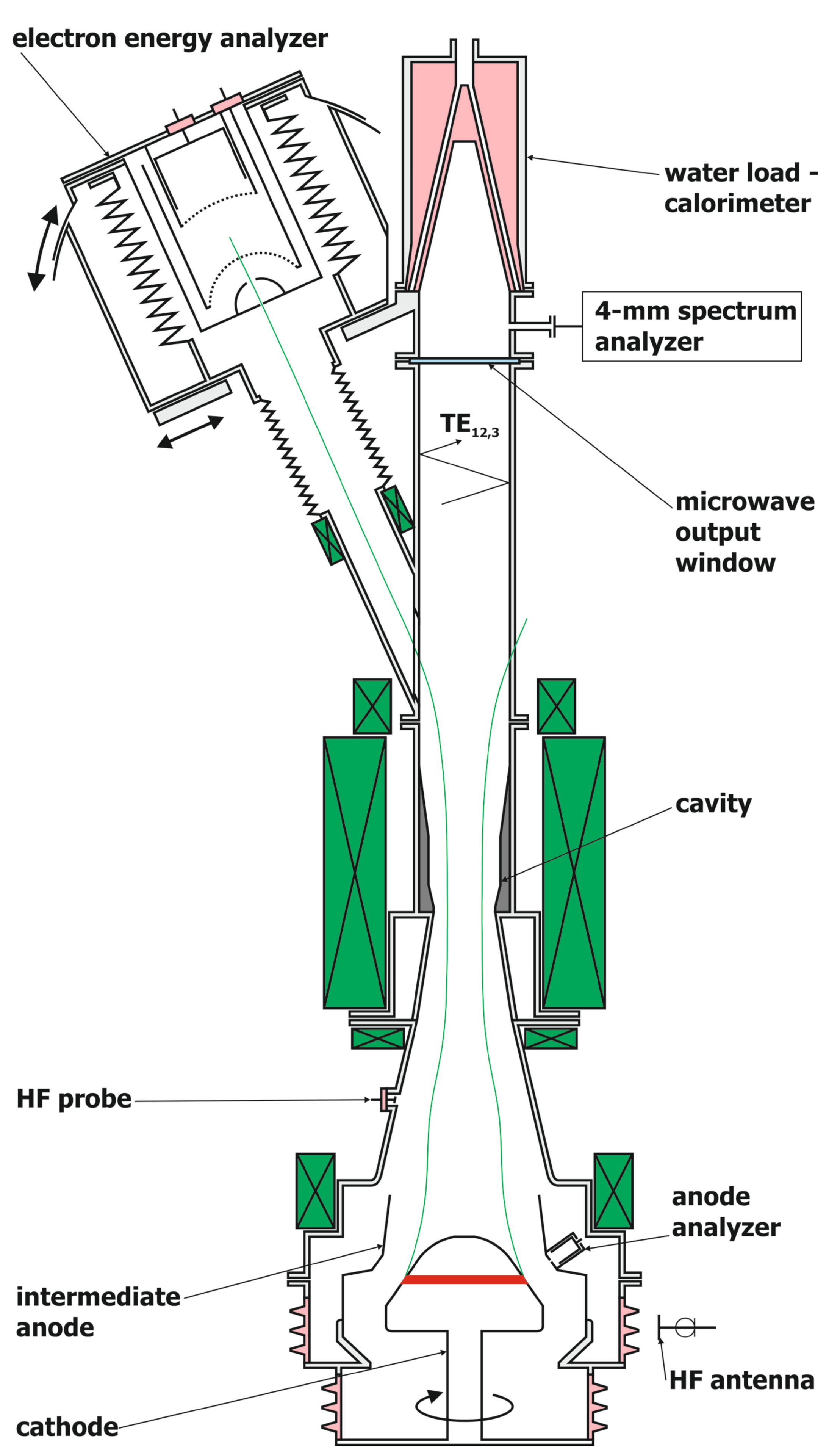

Fig. 1. Drawing of the 4-mm gyrotron cross section.

Accelerating voltage	U_0 = 30 kV
Beam current	I_b = 10 A
Cavity magnetic field	B_0 = 2.75 T
Magnetic compression	B_0/B_c = 18
Operating mode	$TE_{12.3}$
Operating frequency	f_0 = 74.2 GHz
Pitch factor	α = 1.28

SIMULATION (EGUN code)

Trajectory analysis of a gyrotron EOS with nonuniform cathodes

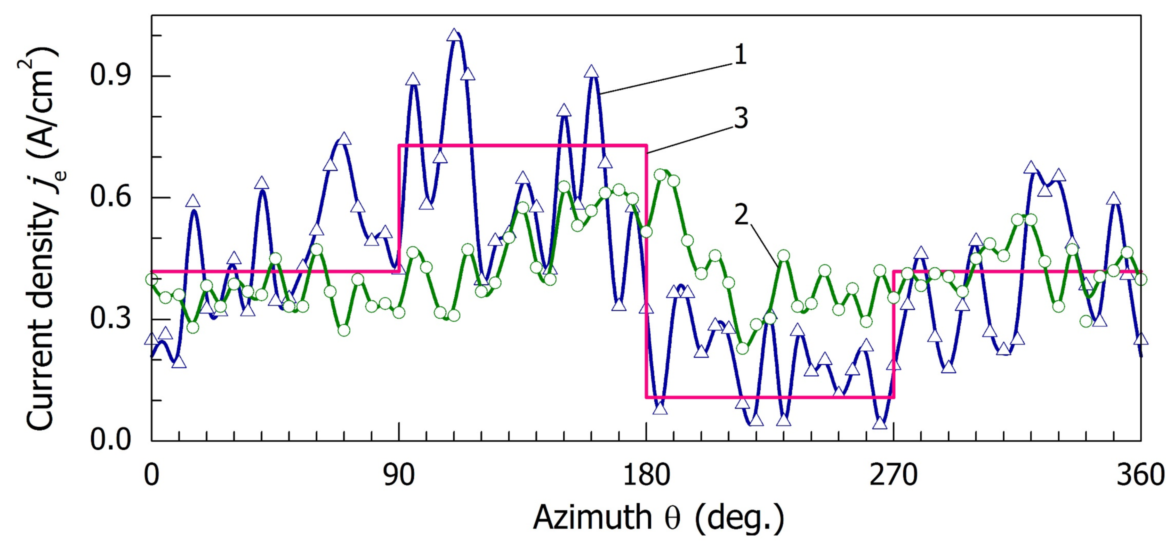

Fig. 2. Azimuthal distributions of emission current density: 1, 2 – measured distributions; 3 – distribution modeling a large-scale nonuniformity of electron emission.

Cathodes	Coeff. of emiss. nonuniformity δj_e (rms-value)	Trans. velocity spread $\delta v_\perp$ (rms-value)
Uniform cathode	0 %	6.37 %
Nonuniform cathodes (Fig. 2)		
• measured distr. # 1	53 %	7.86 %
• measured distr. # 2	23 %	6.63 %
• modeling distr. # 3	53 %	7.95 %

- The value of velocity spread $\delta v_\perp$ is determined at first by the integral coefficient of emission nonuniformity δj_e and weakly depends on shape of the distribution $j_e(\theta)$.

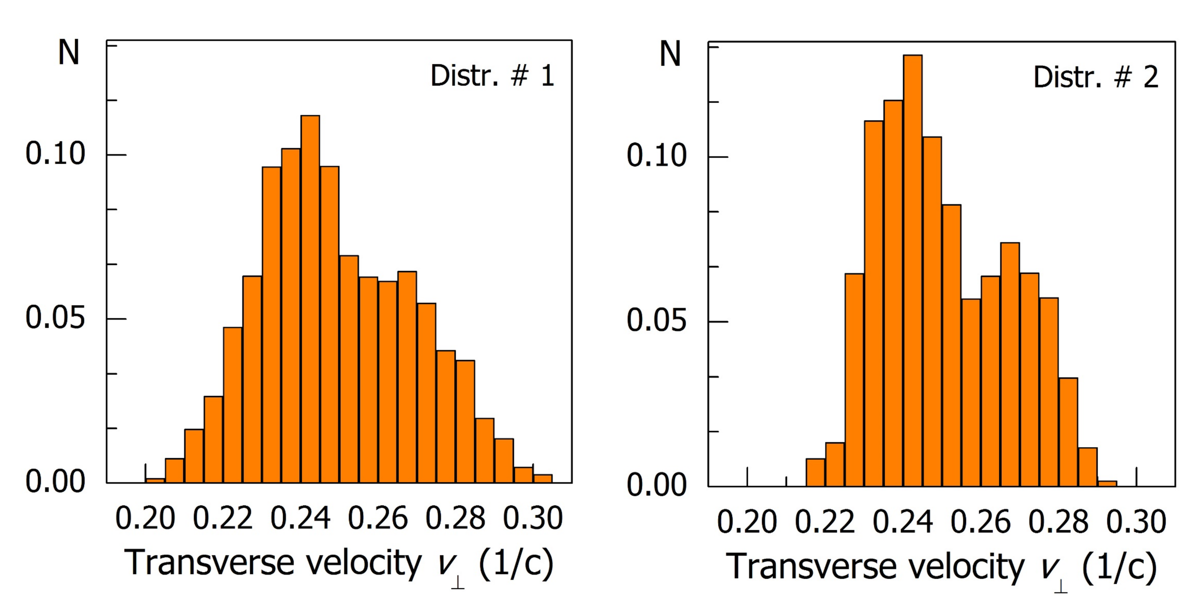

Fig. 3. Velocity distributions for the cathodes with δj_e = 53 % and 23 % (distr. # 1 and # 2 in Fig. 2).

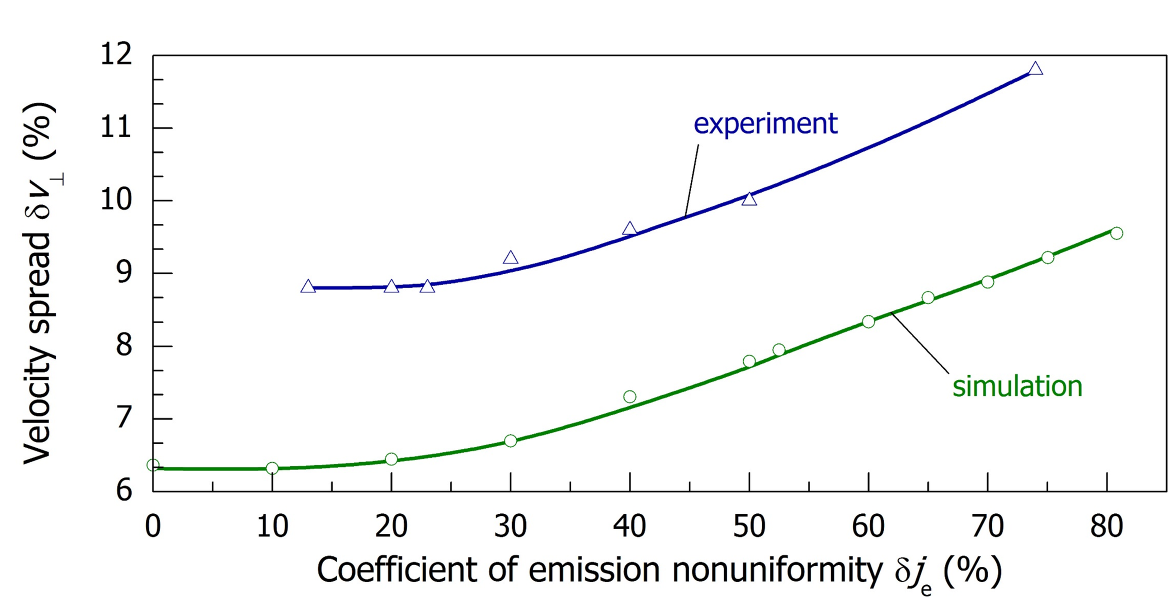

Fig. 4. Experimental [1] and theoretical dependencies of transverse velocity spread $\delta v_\perp$ on coefficient of emission nonuniformities δj_e.

Influence of E-field distribution in the gun region on velocity spread

- The method for improvement of HEB quality is based on optimization of the E-field distribution with a multi-sectional control electrode insulated from the cathode (see details in Fig.6) .

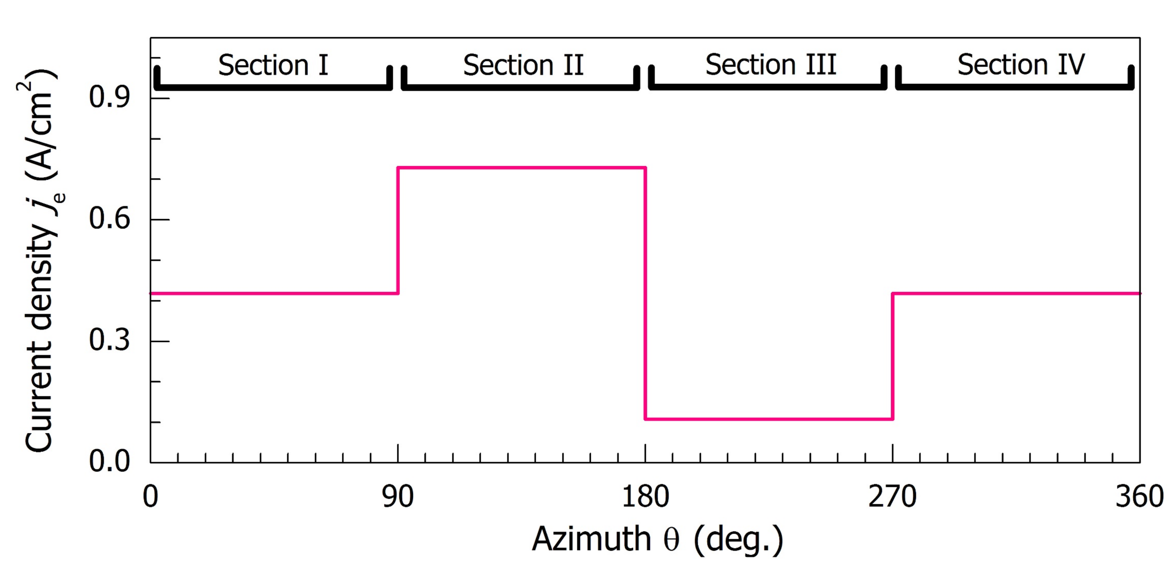

Fig. 5. Positions of the control electrode sections attached to the distribution $j_e(\theta)$.

Results:

- Suppression of the emission nonuniformity effect on the velocity spread was obtained at the potentials of the sections: $\varphi_{III} > \varphi_{I,IV}$ and $\varphi_{II} < \varphi_{I,IV}$;
- At the optimal potentials: $\varphi_{I,IV}$ = –10.4 kV, φ_{II} = –12 kV, φ_{III} = –10 kV (cathode potential φ_c = 0) ⇒ **$\delta v_\perp$ = 2 %;**
- Low spread was achieved mainly by applying a negative voltage on the control electrode for optimization of the E-field distribution **in the *r–z* plane** [3], and also by "compensation" of negative effect of the emission nonuniformities.

[3] O. Louksha, D. Samsonov, G. Sominski, and A. Tsapov, *Technical Physics*, vol. 57, pp. 835-839, June 2012.

EXPERIMENTAL DETAILS AND RESULTS

Design of the cathode assembly

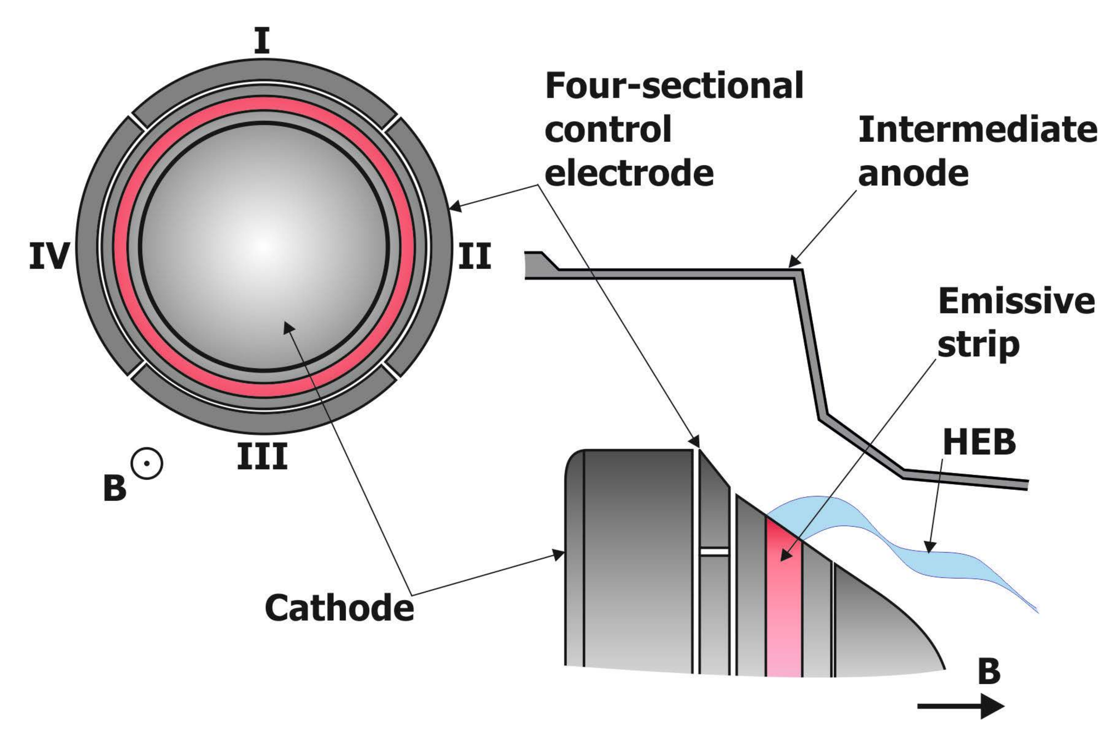

Fig. 6. Drawing of the gyrotron gun region.

- An element of the cathode assembly was replaced by a control electrode consisting of **four electrically isolated sections** shifted one from another in azimuthal direction.
- Section I was located near the emitter area with reduced emission (caused by inhomogeneity of heating of the emitter due to a gap in the cathode heater winding).

Measurements

Suppression of the parasitic low-frequency oscillations:

- In the case of **connected** control sections (Scheme 1) the E-field distribution is azimuthally quasi-uniform.
  For this scheme, we observed the reduction of LFOs intensity with decreasing control voltage (– 5 kV ≤ U_{cont} ≤ 5 kV), which can be generally explained by decreasing pitch factor and velocity spread [3].
- Additional suppression of LFOs (in comparison with Scheme 1) was achieved when the azimuthal distribution of electric field in the gun region **correlated** with the azimuthal distribution of cathode emission current density $j_e(\theta)$.
  Improved HEB quality with **increased** pitch factor (α ~ 1.55) and **suppressed** LFOs was provided by Scheme 2 with potentials of the control sections:
  $\varphi_{I,II,IV}$ = 2.25 kV,
  φ_{III} = 3 kV (cathode potential φ_c = 0).
  Improvement of the HEB quality is a result of the decrease of velocity spread caused by non-uniformities of cathode emission and potential depression in the gun region.

Enhancement of the gyrotron efficiency:

- The gyrotron efficiency η_{max} **= 46 % (without a depressed collector)** was achieved in Scheme 2 with optimal potentials of the control sections providing the high quality HEB with reduced LFOs amplitude and increased pitch factor.

CONCLUSION

New data on the effect of cathode emission nonuniformities on gyrotron electron beam quality were obtained.

Theoretical and experimental data indicate perspectives of the developed method for control of electric field distribution in the MIG near-cathode region to improve quality of the electron beam in gyrotrons through suppression of the parasitic low-frequency oscillations.