

Non-adiabatic electron-optical system for 170GHz/1MW/CW gyrotron

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Introduction

The classical scheme of a gyrotron's electron-optic system (EOS) employs an adiabatic magnetron injection gun (MIG) [1] to form a helical electron beam (HEB) with the oscillatory energy and the velocity spread of electrons good enough for high efficiency generation of microwaves. From the condition of the stability of the electron beam in the trapped configuration of the magnetic field distribution it follows that the maximum pitch factor increases when the velocity spread goes down. Therefore, the decreasing of the velocity spread is the most important approach for improving the gyrotron's efficiency, especially because the spread tends to grow with increasing of the power and the operating frequency of the device. In the MIGs of millimeter and sub-millimeter wave tubes the most essential factors contributing to the velocities spread are the presence of the initial thermal velocities of electrons and, more importantly, the emitter's roughness. One of the possible ways to decrease the influence of the mentioned factors is to use a non-adiabatic scheme for HEB formation [2]. In this case a rectilinear beam is formed initially (fig. 1) and, as a result, the influence of these factors becomes small, which makes it possible to significant increase the gyrotron's efficiency.

Non-adiabatic electron gun in the temperature limiting regime

Below a version of a non-adiabatic EOS aimed to be used in a 170GHz/80kV/30A gyrotron is considered. Here the initial transverse velocities of the electrons are formed by injection of a rectilinear electron beam at an angle of Ψ to the magnetic field (fig.1). After that the adiabatic compression of the beam in the increasing magnetic field is applied to achieve the desired value of the pitch-factor. The required value of Ψ is provided by corresponding adjustment of the cathode coils current (fig. 1 and 2). The advantage of the suggested scheme is that the value of the pitch-factor may be varied independently of the beam compression ratio, i.e. the beam position in the cavity.

The optimal shape and position of the cathode coils providing minimal energy consumption for specified value of Ψ is found.

Simple analytical formulas and some qualitative considerations to find the preliminary shape of electrodes and gun position with respect to the main coil are presented. For preliminary estimations of the gun's position, the value of the angle Ψ , the cathode-anode gap and the shape of the electrodes, simple physical model based on the energy conservation law, Bush theorem and transverse adiabatic invariant conservation law is applied. The recommendations on the choice the electrodes' geometries providing

close angles of injection into magnetic field of the particles starting from the different positions on emitter are given.

The final gun design (fig. 3) is found on the basis of numerical simulation. The optimization was performed using the software package CST Studio Suite [3] and EPOS [4].

Special attention was paid to avoid the electric breakdown. For this purpose the distances between cathode and first anode, first and second anodes, as well as the radii of the curvature of the corresponding electrodes were optimized (see fig. 4). This ensured the electric field value less than 7.7 kV/mm in any point of the formation system.

The results of numerical simulation showed that the use of this nonadiabatic scheme for formation of a helical electron beam for the 170 GHz / 80 kV / 30 A gyrotron allows one to eliminate the influence of such critical for gyrotron operation factor as the condition of the emitter's surface on the value of the velocity spread and makes it possible to get pitch factors up to 1.6 (instead of 1.2–1.3 for conventional MIGs) at the velocity spread of about 30% (Fig. 5). It makes it possible essential increase efficiency of the device. It is interesting to note that unlike in the MIGs, the pitch-factor increases when the current grows, while the velocity spread changes very smoothly.

Space charge limiting regime of electron gun

The formation of the initially rectilinear beam in the cathode-anode gap allows also to use the beam space charge limiting regime instead of temperature limiting one. It is more convenient for operation due to the improved beam stability and possibility of quick (i.e. inertia-free) control of the beam current.

To ensure the space charge limited current regime, the initial geometry of the electrodes has to be altered because in such regime the strongest space-charge defocusing effect takes place. To compensate the defocusing of the beam, the Pierce like gun shape of electrodes, where the conical surfaces are inclined to the beam at an angle of 67.5°, was used (see Fig. 6).

The simulation results made it possible to find the optimal parameters and geometry of the EOS in the regime of the current limitation by the space charge and to investigate the velocity distribution in the electron beam being formed.

Conclusion

The new version of the non-adiabatic electron-optic system suitable for formation HEBs in high-efficient gyrotrons is considered and optimized. The EOS can be employed both in the temperature limiting and space charge limiting regimes.

Acknowledgements

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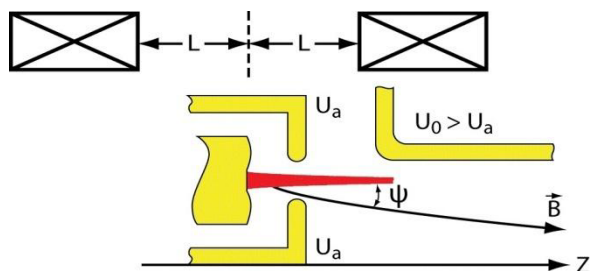


Fig. 1. Principal scheme of the HEB formation region

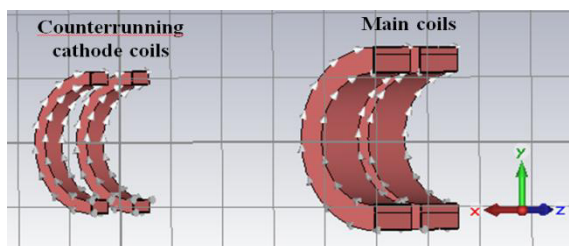


Fig. 2. Principal scheme of the of the gyrotion magnetic system

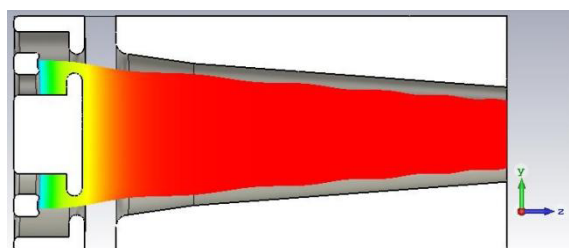


Fig. 3. The configuration of the electrodes in non-adiabatic EOS for 170 GHz/1 MW gyrotion

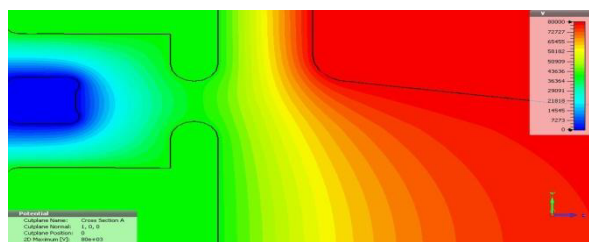


Fig. 4. The map of the equipotential lines in the gun region

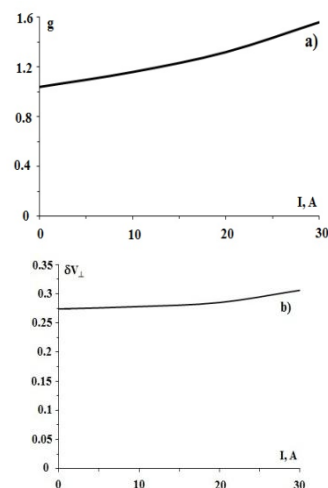


Fig. 5. Dependence of the pitch factor (a) and the velocity spread (b) on the beam current

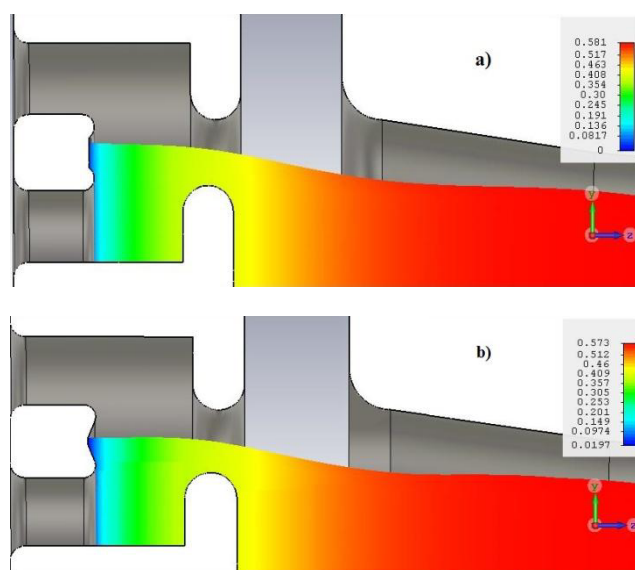


Fig. 6. The configuration of the electrodes in non-adiabatic electron-optical gun for the temperature-limiting emission regime (a) and the space charge limiting regime (b)

References

1. A.L. Goldenberg, M.I. Petelin. Formation of helical electron beams in adiabatic gun// Radiophysics and Quantum Electronics, vol.16, No 6, 1973, pp. 141-149.
2. A.L. Goldenberg, V.N. Manuilov and M.Yu. Glyavin. Electron-Optical System of a High-Power Gyrotion with Non-adiabatic Electron Gun// Radiophysics and Quantum Electronics. 2005. V. 48. No 6. P. 461-465.
3. CST STUDIO SUITE www.cst.com.
4. P.V. Krivosheev, V.K. Lygin, V.N. Manuilov, and Sh.E. Tsimring. Numerical Simulation Models of Focusing Systems of Intense Gyrotion Helical Electron Beams// Int. J. IR MM Waves. 22(8). 1119-1146 (2001).