Design of a Ka-band MW-level High Efficiency Gyroklystron for Accelerators

Li Wang, Kun Dong, Jianxun Wang, Yong Luo  
School of Physical Electronics  
University of Electronic Science and Technology of China  
Chengdu, China, 610054  
wli2012@uestc.edu.cn

Wenlong He, Adrian W. Cross, Kevin Ronald,  
Alan D. R. Phelps  
Department of Physics, SUPA  
University of Strathclyde  
Glasgow, Scotland, UK, G4 0NG  
w.he@strath.ac.uk

Abstract—Design of a three-cavity Ka-band MW-level gyroklystron operated at the fundamental TE$_{02}$ mode is presented in this paper. The initial design of the magnetron injection gun (MIG) and interaction circuit has been completed by using the PIC (Particle in cell) code MAGIC. The PIC simulation shows this gyroklystron can deliver an output power of more than 1.5 MW with a gain of > 35 dB at 36 GHz. The achieved efficiency exceeds 40% when driven by a 95 kV, 45 A beam. The optimized MIG has a transverse velocity spread of less than 2.5% when the velocity ratio is around 1.3.

Keywords—gyroklystron; Ka-band; MIG; interaction circuit

I. INTRODUCTION

Gyrolystrons are vacuum electronic devices (VEDs) which can produce high power in the millimeter and submillimeter wave bands [1-2]. The applications of gyrolystrons include radar systems, remote communication, material processing, etc [3-4]. As a millimeter wave high power source for accelerator, a Ka-band gyroklystron is being studied at the University of Strathclyde and UESTC. The initial design has been completed. A stable output power of more than 1.5 MW is predicted with an efficiency of more than 40%.

II. MIG DESIGN

This Ka-band gyroklystron is driven by a triode type MIG which can generate small-orbit electrons [6]. Compared with the diode type MIG, the triode type version has a better control on the beam parameters, especially the beam velocity ratio ($v_t/v_z$, where $v_t$ and $v_z$ are transverse and axial velocity components, respectively.) [7]. By adjusting the modulating anode voltage, the velocity ratio of the electron beam can be fine-tuned without incurring obvious deterioration of the velocity spread. The configuration of this Ka-band triode type MIG is shown in Fig. 1. The electron trajectories are denoted in red lines. A circle of dielectric material is mounted inside the waveguide wall at the gun exit to avoid exciting parasitic modes.

The simulation results show that all electrons have passed the gun tunnel without any interception. The optimized beam transverse and axial velocity spreads are less than 5% when the the velocity ratio is maintained around 1.3. The average beam guiding center radius is 2.25 mm. The beam current and voltage are 45 A and 95 kV, respectively. The optimized parameters of the gun are summarized in TABLE I.

![Fig. 1. Beam trajectories and gun configuration of Ka-band MIG.](image)

<table>
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<th>TABLE I MIG PARAMETERS</th>
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<tr>
<td>Parameters</td>
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<tr>
<td>Cathode angle $\phi_c$ (deg)</td>
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<td>Emitter width $L_s$ (mm)</td>
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<td>Emitter average radius $R_c$ (mm)</td>
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<td>Current $I_0$ (A)</td>
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<td>Axial velocity spread $\Delta v_z$ (%)</td>
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<td>Mean guiding center radius $r_{go}$ (mm)</td>
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Fig. 2 shows the dependence of velocity ratio $\alpha$ and transverse velocity spread $\Delta v_t$ as functions of modulating anode voltage $V_m$. As $V_m$ grows from 37.5 kV to 38.9 kV, $\alpha$ almost linearly increases from 1.1 to 1.4 due to the transverse acceleration of the modulating anode, while $\Delta v_t$ slightly varies around 2.5%. The results of sensitivity studies show that the MIG can be operated stably within reasonable parametric windows, which demonstrates a robust MIG design.
III. INTERACTION CIRCUIT DESIGN

According to application requirements of the University of Strathclyde, the Ka-band gyrokystron employs a three-cavity configuration. A dielectric material has been applied to overcome mode competition problems. The electron beam is tuned by the injected microwave in the first cavity and the bunching is strengthened in the second cavity. Finally in the third cavity, most electrons lose their energy and the microwave radiation is amplified. Fig. 3 shows the configuration of the interaction structure as well as the bunching process of the electron beams. A distinct change in the electron status is observed in the output cavity, where the efficient beam-wave interaction occurs. In the collector zone, under the force of declining magnetic field, the electron beams and amplified microwave are well separated and the residual electrons are collected by the inner walls.

The evolution of the relativistic factor gamma of electron beam as a function of axial distance is given in Fig. 4. It is shown that when entering the output cavity, most of the electrons begin to lose their energy and the electrons are well bunched with the input signal amplified effectively.

The evolution of output power with regard to the simulating time is given in Fig. 5. After 10 ns, the output power is stabilized at 1.9 MW. A pure TE_{02} mode has been amplified in the output cavity. The Fourier transformation of angular electric field at the output port shows there is a distinct frequency component of 36 GHz existing in the frequency spectrum. No other frequency components are found except a relatively weak 2nd harmonic frequency component of 72 GHz.

IV. CONCLUSION

A design of a Ka-band gyrokystron has been accomplished by using PIC simulations. Fabrication and test of the cavities will be completed in the near future.
REFERENCES


