Electron gun design for a 170 GHz megawatt-level corrugated coaxial gyrotron

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Abstract— **This paper presents the design of a triode type magnetron injection gun (MIG) for a 170 GHz megawatt-level corrugated coaxial gyrotron. The genetic algorithm (GA) is introduced to optimize the beam quality. According to the design acquirements, the predicted transverse velocity spread is 3.03% with a transverse-to-axial velocity ratio of 1.3. The preliminary design procedure is accomplished by an in-house developed code. A multi-objective genetic algorithm (MOGA) code GUNOP written by MATLAB is used to perform the optimization. 2-D electron trajectory code EGUN and 3-D CST particle studio (CST-PS) code are employed to do the calculation and simulation. The results agree well with each other. The sensitivity analysis has also been carried out to estimate the practical operation stability.**

INTRODUCTION

Gyrotrons are capable of generating hundreds of kilowatts of electromagnetic (EM) power in the millimeter and sub-millimeter wave regime [1]. By adopting a longitudinal corrugated tapered insert inside the cavity, the coaxial gyrotron can effectively suppress the mode competition and eliminate the restrictions of voltage depression and limiting current [2].

As a crucial part of the gyrotron, MIG provides the hollow electron beams to interact with the EM wave. Triode type MIG has a (modulating anode (M-anode) and an accelerating anode (A-anode)). Fig. 1 gives the schematic view of triode type MIGs. By tuning the M-anode voltage in triode type MIG, one can readily acquire the desired velocity ratio (defined as $\alpha = v_t/v_z$, v_t and v_z are transverse and axial beam velocity components, respectively). This paper presents the design of a triode type MIG for a 170 GHz megawatt-level corrugated coaxial gyrotron. The design procedure is given in detail. A GA based code GUNOP is introduced to optimize the beam parameters. A 2-D beam trajectory code EGUN is adopted to do the simulation and optimization [3]. 3-D software CST-PS is employed to verify the results.

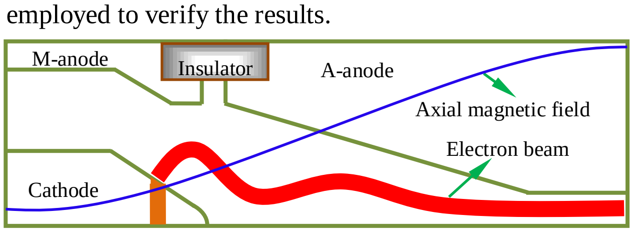

Fig. 1 Schematic views of triode type MIGs.

DESIGN PROCEDURE of the MIG

Taken from [3], the specifications of this coaxial gyrotron are summarized in Table I. The $TE_{31,12}$ mode, which lies in a relative sparse spectrum, is chosen as the operating mode to weaken the mode competition. The electron beam is launched at the first radial maxima of the transverse electric field, corresponding to a radius of 9.48 mm. Considering the electronic efficiency of 48.4% and output power of 1.716 MW, the electron beam is expected to give more than 3 MW power. The operating current is 48 A and voltage is 73.5 kV. Furthermore, a moderate velocity ratio of 1.3 with a transverse velocity spread of ≤ 5% is the design target.

TABLE I
SPECIFICATIONS of the COAXIAL GYROTRON

Operating mode	$TE_{31,12}$
Beam voltage (V_a)	73.5 kV
Beam current (I_b)	48 A
Output power (P_{out})	1.716 MW
Efficiency (*eff*)	48.4%
Magnetic field (B_0)	6.64 T
Beam radius (r_{g0})	9.48 mm
Electron velocity ratio (α)	1.3
Velocity spread ($\Delta\beta_t$)	≤ 5%

An in-house code is developed to determine the initial parameters of the MIG. The code mainly adopts a synthesis approach of MIG design which makes use of the analytical trade-off equations derived by Baird and Lawson [4].

DESIGN OPTIMIZATION of the MIG

Simulated results show that the previous beam quality is poor, so we must perform the deeper optimization. Manual calculations are time-consuming, and sometimes, the results may not satisfy our demands. To perform the optimizations efficiently and automatically, GA is employed. GA is an optimizing method which is based on the biology evolutionary theory driven by natural selection [5]. Based on the concept of GA, a multi-objective GA code written by MATLAB is accomplished. The population size is set as 100. Table II lists the final gun dimensions and optimized beam parameters. The final beam transverse velocity spread is 3.03% when the velocity ratio is kept at 1.29. To verify the EGUN results, CST-PS code is introduced to simulate the MIG in three-dimensions. The CST used magnetic field data is exported from EGUN and other parameters are guaranteed the same with EGUN. Fig. 2 shows the radial beam position at the MIG exit. It is revealed that the average beam radius is about 9.5 mm with a small position spread. Further calculations show that the transverse velocity spread is approximately 3.67% with a velocity spread of 1.32. The results obtained separately by EGUN and CST-PS are in good agreement.

TABLE II

Gun Dimensions and Optimized Beam Parameters

Mean emitter radius (r_c)	42.4 mm
Magnetic compression ratio (f_m)	24
Emission current density (J_c)	6 A/cm^2
A-anode voltage (V_a)	73.5 kV
M-anode voltage (V_m)	51.1 kV
Magnetic field at interaction region (B_0)	6.64 T
Magnetic field at cathode (B_c)	0.278 T
Beam guiding center radius (r_{g0})	9.47 mm
Velocity ratio (α)	1.29
Transverse velocity spread ($\Delta\beta_t$)	3.03%

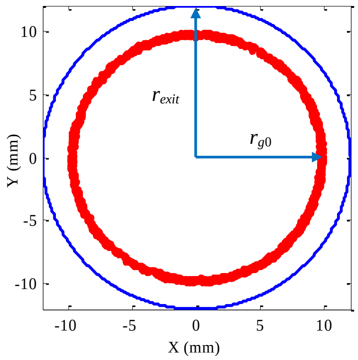

Fig. 2 Radial beam position at MIG exit calculated by CST-PS (r_{exit} is the MIG exit radius)

Sensitivity Study

The real conditions are different from the nominal in the practical operation of gyrotrons [6]. It is necessary to perform the sensitivity study. Fig. 3 plots the effect of the variation of cathode magnetic field B_c and M-anode voltage V_m on the electron beam quality parameters. As illustrated in Fig. 3(a), the beam velocity ratio α is sensitive to the cathode magnetic field. When B_c varies from 0.275 T to 0.281 T, α grows significantly from 1.16 to 1.4. Transverse velocity spread $\Delta\beta_t$ also increases, but never exceeds 4%. Fig. 3(b) shows the parametric dependence of beam quality on the M-anode voltage α is almost linearly increased with the increase of V_m as shown in Fig. 3(b).

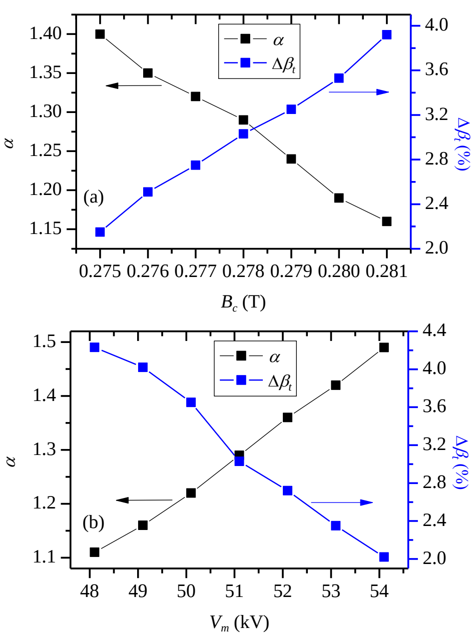

Fig. 3 Beam parameters as functions of (a) B_c, (b) V_m.

Conclusion

This paper is aimed at presenting an optimal design of a triode type MIG for a 170 GHz megawatt-level corrugated coaxial gyrotron by introducing the genetic algorithm method. A high-quality electron beam with a transverse velocity spread of 3.03% and velocity ratio of 1.29 is obtained. The design results acquired by EGUN are validated by CST-PS. The results agree with each other well. Sensitivity analysis has also been performed to demonstrate the gun reliability in real operation.

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