Electron Gun Simulation for 95 GHz Gyrotron

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Abstract: *A triode type Magnetron Injection Gun (MIG) for a 2 MW, 95 GHz Gyrotron has been designed by using commercially available code EGUN and another in-house developed code MIGANS. The operating mode of the gyrotron is $TE_{24,8}$ and it is operated in the fundamental harmonic. The operating voltages of the modulating anode and the accelerating anode are 61 kV and 85 kV respectively. The parametric dependences of modulating anode voltage and cathode magnetic field on the beam quality have also been studied.*

Keywords: Gyrotron, Electron Gun**,** MIG, gyro-device.

1. Introduction

The gyrotron is a high power source of coherent millimeter and sub-millimeter wave radiation. The device is based on the phenomena called Cyclotron Resonance Maser (CRM) instability occurring in the relativistic gyrating electrons during the interaction with the RF [1]. The gyrotrons are widely used as the source of high power millimeter/sub-millimeter wave radiation in the Electron Cyclotron Resonance Heating (ECRH) in plasma fusion, THz spectroscopy, heat treatment of the ceramic materials etc. A high power and compact source of 35/95 GHz frequency is required for the applications like, high power communication, cloud mapping, whether monitoring, security etc. The gyrotron is the device which can generate high output power at 95 GHz frequency with high efficiency.

An important component of the gyrotron is the electron gun, which forms a beam of electrons with the high transverse velocity and the low velocity spread. The triode type MIG with a modulating anode and an accelerating anode has been designed. Three computer codes (one commercially available code EGUN and other two are in-house developed) have been used for design and analysis of the MIG.

2. Computer simulation

Table 1 shows the basic specifications of the gyrotron. A 4.25 MW triode-type electron gun (simply called Magnetron Injection Gun) having the beam voltage (V_0) = 85 kV, the beam current (I_0) = 50 A and transverse to axial velocity of electron beam (α) =1.41 is designed for this gyrotron. The initial gun parameters, namely, the cathode radius (r_c), the cathode-modulating anode spacing (d_{ac}), the emitter current density (J_c), the electric field at the cathode (E_c), the cathode angle (Φ_c), etc. are obtained from the analytical trade-off equations.

The commercially available code EGUN [2] and the in-house developed code MIGSYN and MIGANS [3] are used for the design optimization of the MIG. MIGANS is basically a post processor of the EGUN code and is used to find out the different electron beam parameters like beam velocity ratio, the average transverse velocity spread, the larmor radius (r_l), etc. Considering the technical limits, first the shape of the electrodes including the emitter is optimized for the low transverse velocity spread at the nominal beam parameters and then the electron beam parameters at the interaction cavity are optimized. The numerical calculations are performed in EGUN with 32 beamlets. The optimized values of the modulating anode voltage and the accelerating anode voltage are 61 kV and 85 kV, respectively with 50 A beam current. Fig. 1 shows the optimized geometry of the MIG with the electron beam profile and the magnetic field profile obtained by the EGUN simulations. The optimized values of the different electron beam and MIG geometry parameters by using EGUN are summarized in Table 2.

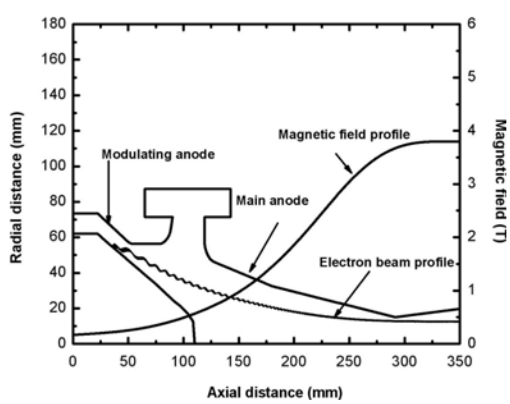

Fig. 1: MIG geometry with electron beam profile.

Table 1: Basic specifications of 95 GHz gyrotron

Frequency (*f*)	95 GHz
Output power (P_{out})	≥ 2MW
Efficiency (η)	≥ 40%, without depressed collector
Operating mode	$TE_{24,8}$
Magnetic field at the interaction region (B_0)	3.8 T

Table 2: The optimized electron beam and MIG geometry parameters

Beam voltage (V_0)	85 kV
Beam current (I_0)	50 A
Average beam radius (r_b)	12.7 mm
Mean radius of the emitter (r_c)	53.8 mm
Slant length of the emitting surface (l_s)	3.4 mm
Slope angle of the emitter (ϕ_c)	28°
Compression ratio (f_m)	17.3
Modulating anode voltage (V_a)	61kV
Cathode current density	3.9 A/cm^2
Average transverse velocity spread ($\delta\beta_\perp$)	1.15%
Transverse-to-axial beam velocity ratio (α)	1.41

3. Sensitivity analysis of the MIG parameters

The electron beam quality is measured in the terms of transverse to axial velocity ratio of gyrating electron beam (α) and the average velocity spread. The beam-wave interaction mechanism depends critically on these parameters.

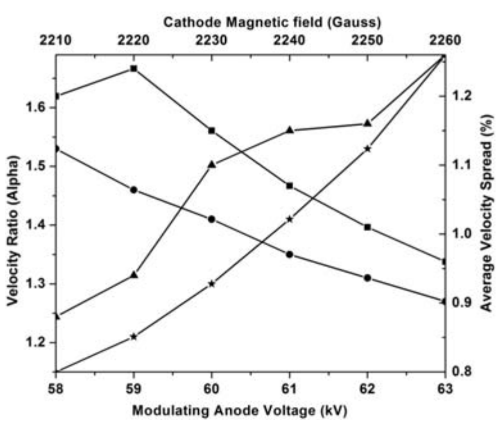

Fig. 2: Dependence of electron beam velocity ratio and average velocity spread on the modulating anode voltage and cathode magnetic field (where the symbols -●-, -■-, -*-, and -▲- represent alpha vs. cathode magnetic field, average velocity spread vs. cathode magnetic field, alpha vs. modulating anode voltage and average velocity spread vs. modulating anode voltage, respectively).

According to the interaction cavity design results, the required value of α at the centre of cavity is 1.4. The electron beam with the desired value of α and minimum transverse velocity spread should reach at the interaction cavity for the efficient beam-wave interaction. The values of α and transverse velocity spread are very sensitive to the modulating anode voltage and the cathode magnetic field [25]. Fig. 2 shows the dependence of velocity ratio and average velocity spread on the modulating anode voltage and the cathode magnetic field.

4. Conclusion

In this paper, the design of a triode-type MIG for 95 GHz, 2 MW gyrotron has been presented. The design of the MIG has been achieved by using the adiabatic trade-off equations and the electron trajectory code EGUN. The electron beam with a low transverse velocity spread at beam voltage = 85 kV, beam current = 50 A is obtained.

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