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Design of Magnetron Injection Gun for 120GHz, 3MW Gyrotron

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Abstract

A high frequency and high power triode-type magnetron injection gun for 120GHz, 3MW gyrotron. The preliminary design has been obtained by using some trade of equations. Computer simulation has been performed by using the commercially available code EGUN and the in-house developed code MIGANS. The operating voltages of the modulating anode and the accelerating anode are 88 kV and 125 kV respectively. The electron beam emitted from cathode and interaction at the cavity with RF structure and the different parameters like transverse velocity spread (Δv) = 3.17%) and velocity ratio (α) =1.48 at beam current = 88A are obtained.

Keywords: Gyrotron, MIG (Magnetron Injection Gun), EGUN Software.

1. Introduction

The microwave tubes has very vast applications and Microwave power at frequencies above about 100 GHz is used for the heating of the magnetically confined plasma in the experimental fusion devices [1,2]. Efficiency of Gyrotron for the generation of the millimetre waves at such frequencies at the desired power levels (3MW) is high. The gyrotron is based on the cyclotron maser interaction between the electromagnetic wave and the gyrating electron beam [3].

In the gyrotron, magnetron injection gun (MIG) is a the source of electron beam, which produces annular electron beam with the required beam parameters. The electrons emitted from the cathode move in the helical path due to the cross electric and magnetic fields. The efficiency of gyrotron depends on the design of magnetron injection gun or source electron beam. Therefore, for getting desired power at desired frequency depends on the electron beam properties at the interaction region, some trade of equations are used for the initial design of the MIG .By using these equations, the gun parameters such as the cathode radius (rc), the cathode-modulating anode spacing (dac), the emitter current density (Jc), the electric field at cathode (Ec), space between both modulating and control anode etc. are estimated. Then the trajectory analysis codes are used for the final optimization of the MIG dimensions for getting desired beam properties on the basis of the operating parameters.

2. Preliminary Design

The design criteria have been set up with respect to the different parameters related to the cathode, electron beam and both anodes. The initial parameters taking for design MIG are frequency and the power. The list of limitation of various parameters in MIG design is given below in table 1.

Table1: Limits of various parameters in the MIG design.

Electric field at cathode (E_c)	20 kV/cm to 50 kV/cm
Potential at first anode (V_a)	< 50% of V_0
Magnetic compression ratio (fm)	10 <fm< 20
Gap factor (Df) (= dac/rlc)	> 3
Current ratio (CR) (Jc /JL)	< 0.2
Velocity spread (Δv) %	< 5%
Cathode angle (ϕ_c)	> 25o
Current density (Jc)	1.1 A/cm2 to 1.2 A/cm2
Transverse to axial velocity ratio (α)	< 1.5
Relativistic factor (γ0)	1.1 to 1.2
Voltage breakdown (Vb) (in vacuum)	< 5 kV/mm

The design of MIG for 120GHz, 3MW gyrotron, the electron beam power has been estimated from the RF output power of 3MW by assuming an RF output efficiency of about 30% for a selected operating mode. The interaction structure calculations determine the magnetic field at the interaction region (B0), the accelerating beam voltage (V0), the beam current (I0), the average beam radius (rb) another beam properties at the interaction region.

For Proper design of MIG, first we need to select the proper mode in the interaction structure. On the basis of the mode selection parameters and the start up scenario in the interaction region. The TE03 mode exhibits high coupling with the gyrating electron beam. The beam current and the beam voltage have been chosen on the basis of the interaction efficiency, the space charge effect at the interaction cavity and the velocity ratio of the electron beam .The nominal beam parameters at the interaction region are shown in Table 2.

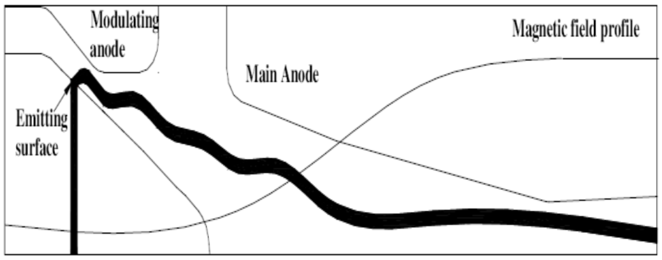
Table 2.Nominal electron beam parameters

Beam voltage (V0)	95 kV
Beam current (I0)	88A
Output power (P0)	3MW
Operating mode	TE0,3
Magnetic field at the interaction region (B0)	4.817T
Average beam radius (rb)	17.64mm
Transverse-to-axial beam velocity ratio (α)	1.48
Maximum transverse($\delta\beta_{\perp max}$)	3.17 %,

Further, using the design criteria presented in Table 1, The cathode-modulating anode and the modulating anode-accelerating anode spacing have been kept as such that the voltage breakdown could not occur. Then, by using the trade-of equations derived by Baird and Lawson [4,5], a computer program MIGSYN has been developed. A detail study has been carried out by using MIGSYN to see the effect of the cathode radius variation on the various MIG parameters. The selection method of the cathode radius range through the observation of its variation on the gap factor (Df), the electric field at the cathode (Ec), the magnetic compression ratio(fm) and the current ratio (Jc/Jl). Within the tolerable limits of these parameters under the design criteria shown in Table 1, the range of the cathode radius has been selected from 60mm to 90mm Any value of the cathode radius within this range can be adopted for design analysis of 120GHz and 3MW gyrotron magnetron injection gun.

Here, the design criteria regarding to the electron beam velocity spread given in Table 1 has not been used in the preliminary design, though it has been used in the electron beam analysis. Fig.1 shows the two dimensional MIG geometry used for electron beam analysis. For the actual synchronization of the electron beam with the RF at the interaction region, the magnetic field is always kept less than the peak magnetic field. Here, the magnetic field at the interaction region has been reduced from the peak value (4.95 T) by a factor of 2.5% giving the value of B0 ≈ 4.817 T. The peak value of B0 at the interaction region has been calculated by using B0 = f (GHz) γ0/28s, where f is the operating frequency, γ0 is the relativistic factor and s is the harmonic number [5].

Figure 1. MIG with the electrode geometry, the beam profile and the magnetic field profile of MIG



3. Simulation And Discussion

Based on the preliminary design, the trajectory analysis has been carried out to optimize the electrode shapes and the electron beam parameters. Various dimensions and the parameters for the trajectory simulation are shown in Table 3. The computer simulation has been performed by using the commercially available code EGUN. The calculations have been performed with 16 beam lets. The main goal of the triode-type MIG design is to launch the electron beam at the first radial maxima of the operating mode at the interaction region with the minimum transverse velocity spread (δβ⊥max). Considering the technical limits, first the shape of the electrodes including the emitter has been optimized for the low transverse velocity spread at the nominal beam parameters and then the electron beam parameters at the interaction region have been optimized. After numerical simulation of the MIG, the electrical parameters have been evaluated with the help of MIGANS code. The EGUN simulation has thus provided the optimized design parameters and the beam profile (Fig. 4, Table 4).For a high current electron beam, the influence of the space charge effect on the velocity spread is an important factor. To reduce the space charge influence, φ (angle between the emitter surface and the magnetic field line) should be greater than 25◦. In this case the laminar beam is formed and, therefore, the velocity spread growth with beam current is reduced [6][7]. Fig. 5 shows the laminar beam profile near the cathode. The calculated value of the maximum transverse velocity spread due to the electron optics is approximately 3.3% at α = 1.48

Table3. Dimensions and parameters used in the trajectory Simulation

Cathode Radius (rc)	80.15 mm
Slant length of the emitting surface (ls)	5.16 mm
Slope angle of the emitter (φc)	28◦
Magnetic field at the interaction region (B0)	4.817 T
Magnetic Compression ratio (fm)	23.96

Table 4.Optimized values of different MIG parameters.

Modulating anode voltage (Va)	88 kV
Control Anode voltage	125kV
Cathode current density	1.1 A/cm2
Maximum transverse velocity spread (δβ⊥)	3.3%
Transverse-to-axial beam velocity ratio (α)	1.48

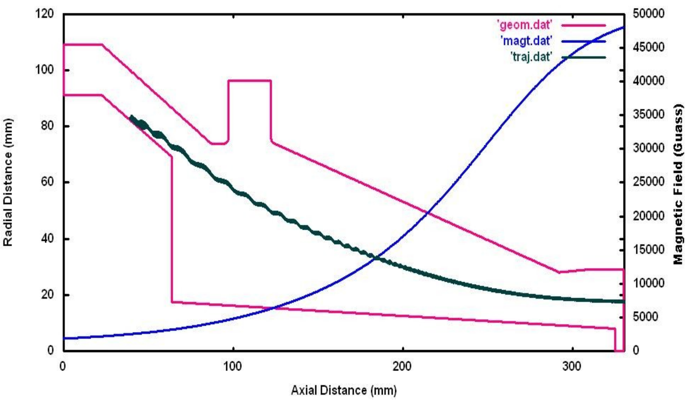


Figure4. MIG with the electrode geometry, the beam profile and the magnetic field profile optimized by using EGUN code.

For the sake of simplicity, the influence of the surface roughness and the cathode temperature on the beam parameters has not been considered in the calculation of the maximum transverse velocity spread. This aspect will be considered in due course of time.

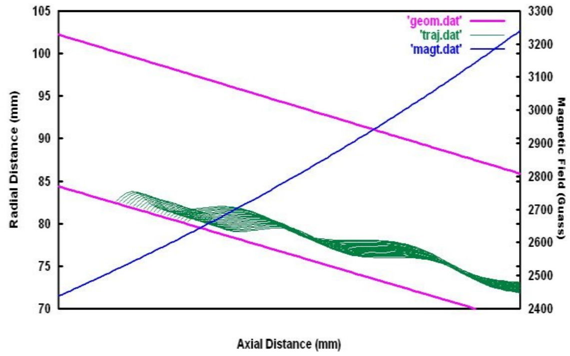


Figure 5. Optimized beam profile near the cathode by using the EGUN code

4. Conclusion

In this paper, the design of a triode-type MIG for 120 GHz, 3MWgyrotron has been presented. The design of the MIG has been achieved by using the trade-off equations and the electron trajectory code EGUN. Good enough quality electron beam with a low transverse velocity spread δβ⊥max = 3.3%) and α= 1.48 at the beam voltage = 95 kV and the beam current = 88A has been predicted. The design obtained by using the EGUN code. The MIG parameters like magnetic field at the cathode centre and the modulating anode voltage affect the beam quality parameters critically while the latter are less sensitive to the magnetic field at the cavity centre and the beam voltage.

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