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Design of MIG for 300 GHz High-Power Pulsed Gyrotron
300 GHz 高出力パルスジャイロトロンの実現に向けた電子銃設計

Yuusuke YAMAGUCHI, Yoshinori TATEMATSU, Teruo SAITO, Naoki YAMADA, Ryosuke IKEDA, Jagadish C. MUDIGANTI, Isamu OGAWA and Toshitaka IDEHARA
山口裕資，立松芳典，斉藤輝雄，山田尚輝，池田亮介，
Jagadish C. Mudiganti，小川勇，出原敏孝

Research Center for Development of Far-Infrared Region, University of Fukui, Fukui 910-8507, Japan
福井大学 遠赤外領域開発研究センター　〒910-8507 福井市文京3丁目9-1

A 300 GHz pulsed gyrotron with a power exceeding 100 kW has been under development. This paper describes the design optimization of a magnetron injection gun for this gyrotron. An optimum geometry of the electrodes is investigated to provide a laminar electron flow with a small velocity spread.

1. Introduction

Gyrotrons are capable of providing high-powers at millimeter and sub-millimeter wave lengths, and widely used in the various fields of physics study and technological use. Recently, development of a high power source in the sub-Terahertz region is expected for the measurement of collective Thomson scattering in the fusion experiments. To achieve simultaneously a higher signal-to-noise ratio and scattering angles sufficient for good spatial resolution, an oscillation power of more than 100 kW is required at the frequency range of 300 ~ 400 GHz [1, 2]. In FIR, Univ. of Fukui, design of over 100 kW tube is currently in progress. The oscillation mode of this gyrotron is the $TE_{14,2}$ at the fundamental harmonic.

In the gyrotrons, formation of a laminar electron beam with a small velocity spread is essential for realization of the high power oscillations. In this study, a design of magnetron-injection gun (MIG) is performed by use of an electron trajectory code EGUN [3].

2. Design of new MIG

The oscillation frequency in the cavity is set at 295 GHz with the magnetic field strength of 11.4 T. In order to achieve the output power of over 100 kW, beam current of more than 10 A is required with the beam voltage of 65 kV. Furthermore, to ensure the high quality beam, the velocity pitch-factor α (the ratio of perpendicular to parallel velocities to the magnetic field line) of 1.2 and the α spread (defined by the formula below) less than 10 % are set as the target design values.

$$\alpha_{spread} \equiv (\alpha_{max} - \alpha_{min})/\alpha_{average}$$

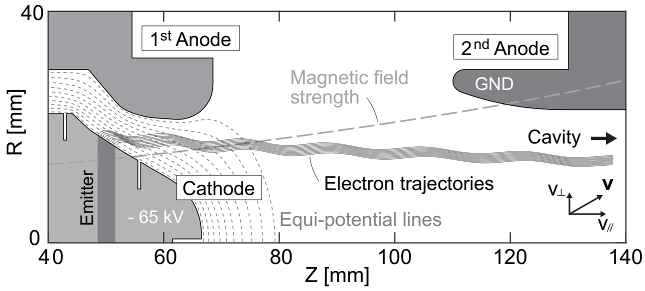

Fig. 1. A schematic diagram of MIG.

A triode-type structure is adopted to control the beam properties without changing the total beam energy. The MIG parameters were initially estimated on the basis of the adiabatic theory. The dimensions of the cavity are 3.4 mm in radius, and 9.0 mm in length. The radius of the electron beam R_b should be 2.42 mm in the cavity in order to couple to the $TE_{14,2}$ mode. The radius of the emitting ring is set to 17.6 mm, from which the guiding center of the electron arrives at the R_b = 2.42 mm in the cavity. In this geometrical design, the magnetic compression ratio between the cavity and the emitting ring becomes 53.2. Figure 1 represents the schematic drawings of the electrodes which are used for the numerical computation of the beam trajectory. The distance between the cathode and first anode of 6.5 mm is derived under the condition, where the applied voltage between the cathode and first anode (V_{KA}) is 25 kV and expected α at the cavity is 1.2. Here, the maximum value of V_{KA} is restricted up to 30 kV to provide an enough electrical insulation, which depends on the structures of the electric terminals located on the outside of the vacuum region.

The design optimization has been conducted by calculating the beam trajectories, the averaged value of α (α average) and α spread at the cavity for the various shapes of the electrodes. An example of the beam trajectories calculated with EGUN is shown in Fig. 1. For the higher beam current, the space charge has stronger effect on the α spread. To reduce the influence of the space charge, formation of a laminar flow becomes important. The degree of the lamination is strongly affected by the slant angle θ of the emission surface to the magnetic field line. The value of θ should be larger than 20 degrees for realizing a well laminated flow [4]. In Fig. 2, the applied voltage V_{KA}, the α spread at the cavity and the degree of the lamination [5] are plotted as functions of the slant angle θ. In the calculations of Fig. 2, the α average at the cavity is kept to 1.2 by adjusting the applied voltage V_{KA}. In Fig. 2, the left side vertical axis corresponds to the required V_{KA} to obtain the α average of 1.2. It is clearly shown that θ has an optimum value at around 28 deg. to suppress the α spread. It has been also confirmed that the α spread decreases with increasing the degree of lamination. In addition, the optimum value of θ depends on the detailed shapes of the first anode and the cathode. Therefore, it is suggested that the formation of a well laminated flow depends not only on the slant angle θ, but also on the spatial distribution of the electric field in between the cathode and the first anode associated with the other shapes of the electrodes. The value of θ is finally determined at 28 deg., and the other shapes of the electrodes have been carefully optimized. The sensitivity of the beam quality to small deviation of the shapes of the electrodes from the designed one is checked.

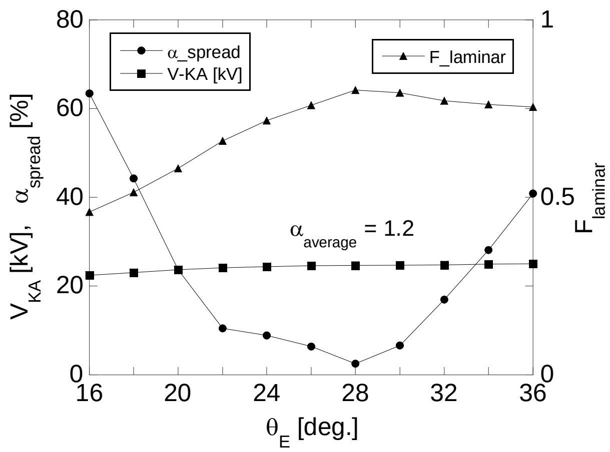

Fig. 2. Variation of the V_{KA}, the α spread at the cavity and the degree of the lamination is given as functions of the slant angle θ. In the calculations, the averaged value of α at the cavity is fixed by changing the V_{KA}.

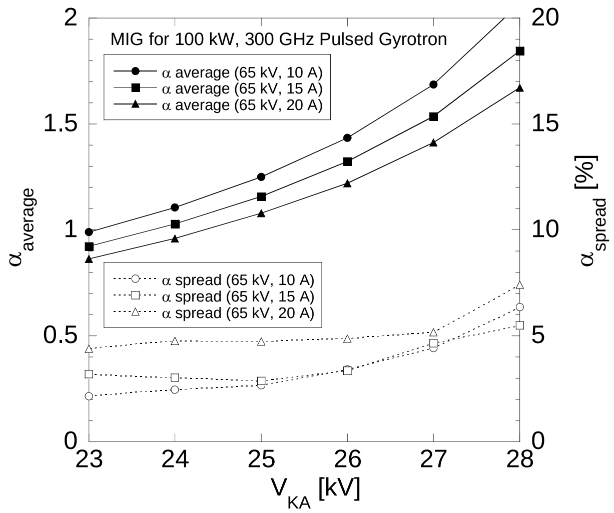

Fig. 3. Calculated pitch-factor α and α spread for 65 kV, 10-20 A electron gun.

As a result of the design optimization, a good configuration of the electrodes is obtained with a wide operation window. In Fig. 3, α average and α spread at the cavity are plotted as functions of V_{KA}. In the parameter range shown in Fig. 3, no mirror reflection of the electrons occurs. The desired value of the α average of 1.2 can be realized even at the beam current larger than 10 A. The α average decreases with increasing the beam current. The reason for this is thought to be the voltage depression in between the cathode and first anode, because of the space charge. Similarly the α spread tends to increase with the beam current, and even with V_{KA}. In any case, very small α spread less than 5 % has been achieved in the expected operating region of α average = 1.0 ~ 1.3. Finally, it is confirmed that the ratio of the beam current density J_b to the Langmuir current density J_L is kept low (J_b/J_L < 20 %) [4]. Besides that, it is checked that the electric field in the vicinity of the emitting surface becomes higher than 3 ~ 4 kV/mm to avoid too strong influence of the space charge forces on the beam properties [6]. An electron gun which is suitable for the new gyrotron has been successfully designed.

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