Parameterization Technique for the Preliminary Gun Design of the EU 170GHz 1MW Conventional Cavity Gyrotron for ITER

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***Abstract*—A preliminary gun design for the EU 170 GHz, 1 MW conventional cavity gyrotron, for the $TE_{32,09}$ mode [1], will be presented. The ASG magnet of the EU 170 GHz, 2 MW coaxial cavity gyrotron for ITER is used for the required magnetic field. A parameterization of the diode gun has been defined. Using the *Ariadne*++ code [2] the geometry has been optimized with respect to several criteria, such as the small velocity spreads, the acceptable width of the beam radius at the cavity, etc. The neutralization effect has been taken into account using a simple model.**

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I. Introduction

Gyrotrons are the leading microwave sources for plasma heating and current drive in magnetic confinement fusion experiments. In a gyrotron, a helical electron beam, formed by a MIG-type electron gun and guided by an external magnetic field, delivers energy to a RF electromagnetic wave (i.e. a TE mode supported by the interaction cavity) through electron cyclotron resonance. The European development of a gyrotron for ITER is focused on a 170 GHz/2 MW/CW coaxial-cavity gyrotron [3]. However, a design of a 170 GHz/1 MW/CW gyrotron, employing a hollow-waveguide interaction cavity, has also been initiated. We report on the gun design of this gyrotron.

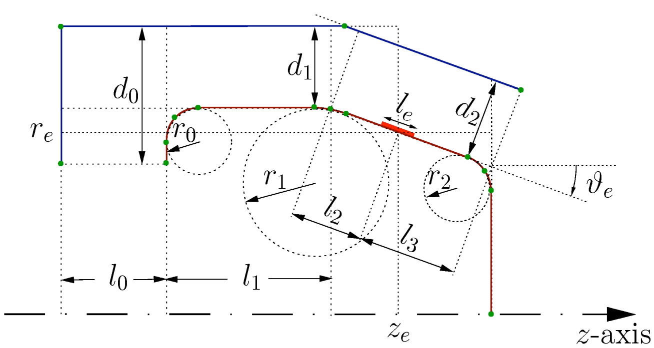

Fig. 1: The parameterization of the cathode and anode surface.

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II. The Gun Parameterization

A set of parameters (see fig. 1) is defined for the rigorous description of diode-based gun geometry. These parameters are categorized as follows: (i) The distance between the emitter and the cavity is determined by the axial position z_e of the emitter. (ii) The cathode shape is defined by the emitter radius r_e, the emitter angle θ_e, the lengths l_1, l_2 and l_3 and the radii r_0, r_1 and r_2 of the circles for the smoothing of the three edges on the cathode surface. The width l_e of the emitter is related to the current density J_e and the beam current I_b by the equation $I_b = 2\pi r_e\, l_e\, J_e$. (iii) Finally, the distance between anode and cathode is defined by the parameters l_0, d_1, and d_2.

The beam tunnel of the gun is automatically generated by the *Ariadne*++ code. The shape of beam tunnel is based on the magnetic field line which passes through the center of the emitter. Using a script file in *Ariadne*++, the gun geometry is automatically generated for any set of parameters. The simulation of a large number of geometries in short time is possible using this technique.

III. The Beam Neutralization Effect

It has been proved experimentally that in long pulse and CW gyrotrons the neutralization effect takes place and it should thus be taken into account for the design of the new gun. A significant number of molecules of the remaining gas in the gyrotron (vacuum is not perfect) are ionized by their collisions with the beam electrons.

This fact generates positive charges (ions) and electrons, which affect the beam properties. The light electrons are evacuated in a short time but the heavy ions remain in the beam region, neutralizing the space charge of the beam electrons. In the case of a gyrotron with depressed collector, a potential well for the electrons is configured between the emitter and the collector. Experiments have shown that even in this case the neutralization effect at the cavity takes place [4]. There are two possible mechanisms for this fact which are the following: (i) a diffusion process takes place when the density of the electrons in the potential well increases significantly, and/or (ii) ponderomotive forces, due to the high frequency electric field at the cavity, affect the electron trajectories. There are many unanswered questions about the neutralization effect and for this purpose a comprehensive study has been initiated. To confront the difficulty of different time scales of electrons and ions trajectories, the *Ariadne++* code has been upgraded to an hybrid code: the electron beam is simulated using a trajectory algorithm while the ion trajectories are calculated using the PIC technique. The next step is the development of an appropriate model for the evacuation of the electrons generated by the ionization process. We hope that this study will shed new light in this problem. Here, in order to take into account the neutralization effect a very simple model proposed by S. Illy is applied. Due to the high electric field in the diode vicinity, the ions fall on the cathode wall immediately after their generation and therefore the beam neutralization does not take place close to the cathode. So, the contribution of the electron beam space charge is significant on the electron trajectories at the diode region. On the other hand, according to the experiments, the beam is fully neutralized at the cavity and the contribution of space charge is negligible. An appropriate function is defined representing the contribution of the electron beam charge. It has the value one at the diode and zero at the cavity region. The neutralization effect is taken into account by multiplying the space charge of the macro-electrons by the contribution function.

Several simulations showed that the beam parameters at the cavity are not significantly affected by the shape of the contribution function at the beam tunnel region (the intermediate region between the emitter and the cavity). For the design of the gun a contribution function with a smooth transition from the value one to value zero was considered.

IV. The Preliminary Gun Design

For the design of the preliminary gun the ASG magnet of EU 170GHz/2MW/CW coaxial gyrotron is considered. The ASG magnet consists of eight coils: four main coils, two bucking coils and two gun coils. The required magnetic field at the cavity for the excitation of the $TE_{32,09}$ mode is 6.76 T. This magnetic field is achieved by applying a current of 87.95 A in the main and the bucking coils of the ASG magnet. In the preliminary design zero current is applied in the gun coils.

For the design of the new gun a large number of geometries has been checked. The proposed geometry is shown in fig. 2. The beam is simulated for the following three different cases of neutralization: (I) the beam is not neutralized (which is the case of start-up), (II) the beam is fully neutralized only at the cavity (using the simple model described earlier), and (III) the beam is fully neutralized along the whole beam path (I_b = 0 A). The beam parameters at the cavity for the three neutralization cases are given in the following table:

beam parameters	**I**	**II**	**III**
radius r_{gc}	0.950 cm		
width Δr_{gc}	0.22 mm ≈ λ/8		
transverse velocity β_t	0.398	0.394	0.417
velocity spread $\delta\beta_t$	1.29 %	0.87 %	0.07 %
velocity ratio α	1.48	1.29	1.51
relativistic factor γ	1.1406	1.1540	1.1546
beam voltage V_b	71.81 kV	78.64 kV	79 kV

V. Conclusion and Discussion

A new gun for the EU 170 GHz, 1 MW conventional cavity gyrotron has been presented. The preliminary gun has been designed for the $TE_{32,09}$ mode. The beam neutralization effect has been taken into account using a simple model. The beam satisfies all the criteria for the $TE_{32,09}$ mode excitation when the neutralization effect takes place. During the start up the neutralization does not take place and the beam parameters at the cavity have some deviation from the nominal values. The velocity ratio is 1.48 instead of 1.3 and the beam voltage is 71.81 kV instead of 79 kV due to the voltage depression. The effect of this deviation on the mode excitation process should be studied using a multi-mode, self-consistent interaction code. The beam velocity spreads are small (<1.5% rms for the transverse velocity) for all neutralization cases.

A remarkable result of this numerical study is that the velocity spreads are strongly dependent on the emitter angle θ_e and the nose length l_3 of the cathode. This is shown in fig. 3 for the full-length neutralization case. The appropriate choice of both parameters ensures the small velocity spreads of the beam at the cavity.

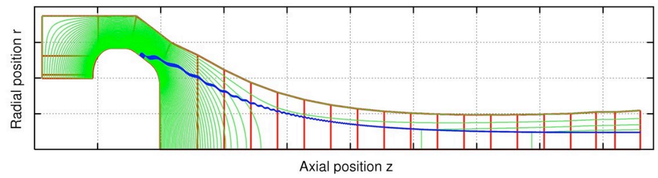

Fig. 2: The geometry of the new gun

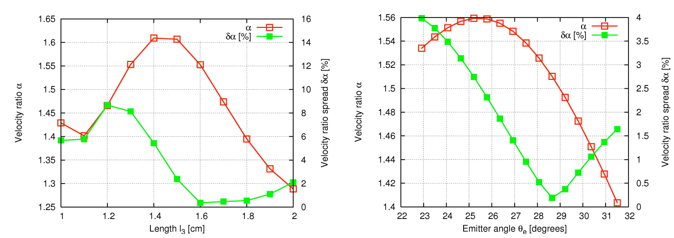

Fig. 3: The average value α and the spread δα of the beam velocity ratio at the cavity versus the nose length l_3 (left) and the emitter angle θ_e (right) of the cathode.

References

[1] K. A. Avramides *et al.*, "Mode Selection for a 170 GHz, 1 MW Gyrotron", 35th EPS Plasma Physics Conference, Conference Proceedings, Hersonissos, Crete, Greece, 1-13 June, 2008.

[2] Pagonakis and J. L. Vomvoridis, "The self-consistent 3D trajectory electrostatic code Ariadne for gyrotron beam tunnel simulation", 29th Joint Int. Conf. Infrared Millim. Waves and THz Electr., Karslruhe, Germany, Conference Digest pp. 657-658, 2004.

[3] J.-P. Hogge *et al.*, "The European 2 MW, 170 GHz coaxial cavity gyrotron for ITER", Joint 32nd Int. Conf. Infrared Millimeter Waves and 15th Int. Conf. THz Electronics, Conference Digest 38, 3-7 September 2007, Cardiff, UK.

[4] K. Sakamoto, at all, Achievement of robust high efficiency 1 MW oscillation in the hard-self-excitation region by a 170 GHz continuous wave gyrotron, Nature Physics 3, pp. 411-414, 2007.

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