STRONG MICROWAVES IN PLASMAS

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35 GHz GYROTRON CONSTRUCTION AT INPE

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ABSTRACT

The conceptual design of a 35 GHz gyrotron for plasma heating experiments is presented. This gyrotron has been designed for pulsed operation in the TE_{021} mode. Under the soft self-excitation condition, the maximum efficiency is calculated as 40% with an output power of 100 kW.

Current experimental work is being done on the construction of all the components and testings of the various subsystems are well underway. Also, techniques for ceramic-to-metal sealing are being developed as well as different types of thermoionic material for the cathode emitting band.

1. INTRODUCTION

The high power millimeter radiation generated by gyrotrons can be coupled to fusion plasmas to heat them, drive current and suppress instabilities. These are the main motivation for the gyrotron development program [1-6] under way at the Brazilian Institute for Space Research (INPE).

The device is composed of three main parts (Fig.1): the electron gun, the resonant cavity and the collector.

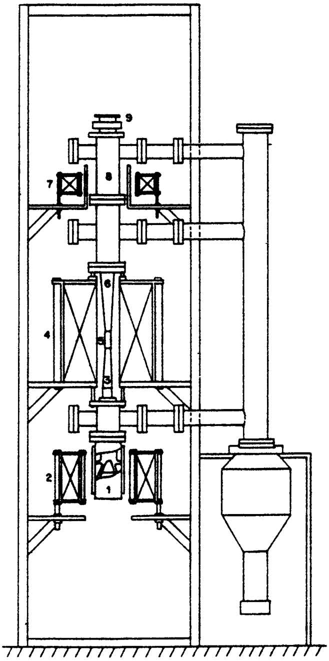

Fig. 1 - Schematic of the 35 GHz gyrotron

1 - electron gun
2 - gun magnetic coil
3 - drift tube
4 - main magnetic coils
5 - resonant cavity
6 - output taper
7 - collector magnetic coil
8 - collector
9 - output window

2. ELECTRON GUN

The electron gun must generate a beam with high transverse energy and low velocity spread. A way to reducing velocity spread is to use guns with laminar beams. The electrode configuration and the electron trajectories are shown in Fig. 2.

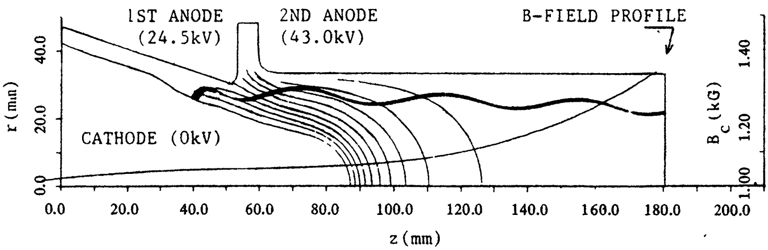

Fig. 2 - Electrode configuration and electron trajectories for the 35 GHz gyrotron electron gun

For this gun, the total beam current is I = 5.0 A. In the drift tube, the beam undergoes magnetic compression. At entrance to the cavity the electron velocity ratio is $\alpha = v_\perp / v_\parallel = 1.5$ and the total dispersion is $\Delta v_\perp / v_\perp = 2.0\%$ [2]. The engineering drawing is shown in Fig. 3.

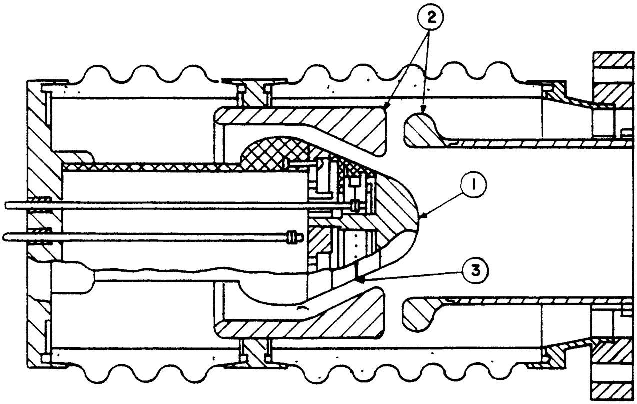

Fig. 3 - Cutaway view of the gyrotron electron gun

1 - molybdenum cathode; 2 - titanium anode; 3 - electron emission ring

Two types of material such as Ba/Sr oxides and tugsten-molybdenum porous matrix impregnated with barium aluminate are being investigated for the electron emitting band [6]. These materials can provide the required current densities of 2.5 and 5.0 A/cm^2 , respectively.

3. RESONANT CAVITY

The ressonant cavity is a conventional one made up of truncated cones with a uniform mid-section [1]. The design parameters give a eigen frequency of 34.918 GHz and a diffraction quality factor of Q = 945.

The chosen TE_{021} mode is characterized by low ohmic losses on account of the azimuthal symmetry, and is relatively free from mode competition.

The cavity is constructed by using electroforming process through acid copper sulphate baths. In the final step a chemical coating with gold or silver should be applied.

4. COLLECTOR AND MAGNETIC COIL SYSTEM

The collector consists of a copper tube of 6.35 cm internal diameter and 4 mm thickness. By means of auxiliary solenoids, the electron trajectories can be controlled to some extent in order to restrain the energy flux density to a maximum tolerated value of 2 kW / cm^2.

The magnetic field required for gyrotron operation is produced by three systems of coils to provide high field homogeneity in the cathode cavity and collector regions (Fig. 4).

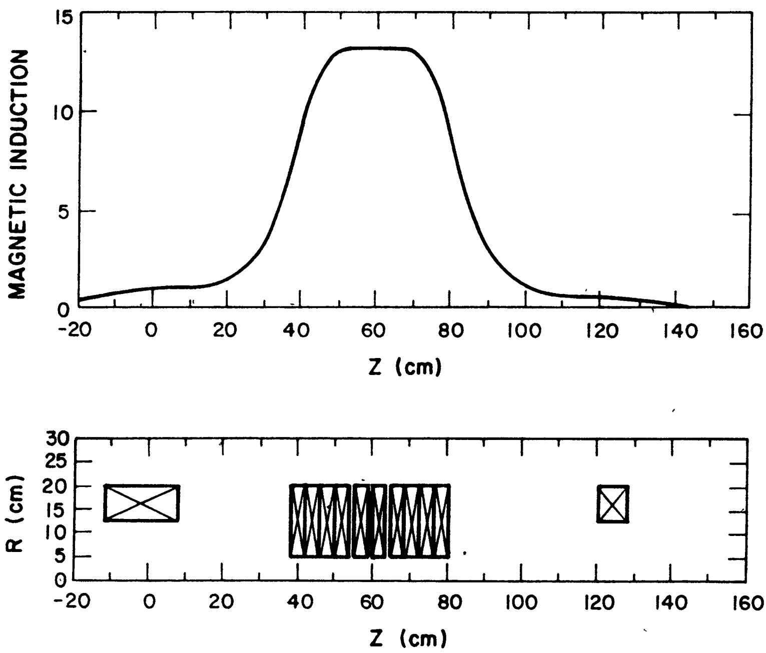

Fig. 4 - Axial profile of the magnetic induction and the respective solenoid system

The main system is made up of 20 water cooled solenoids fed by a current of 1 kA, which produces a flat top magnetic field axial distribution with peak value of 13.5 kG over a length of 13 cm. In the collector region, where there is a plateau of 0.65 kG, the beam guiding center radius is equal to the internal collector radius of 3.18 cm.

By this arrangement, the collector system shown in Fig. 5 operates as a magnetic energy filter, in the sense that the impact position of each electron depends upon its remaining energy.

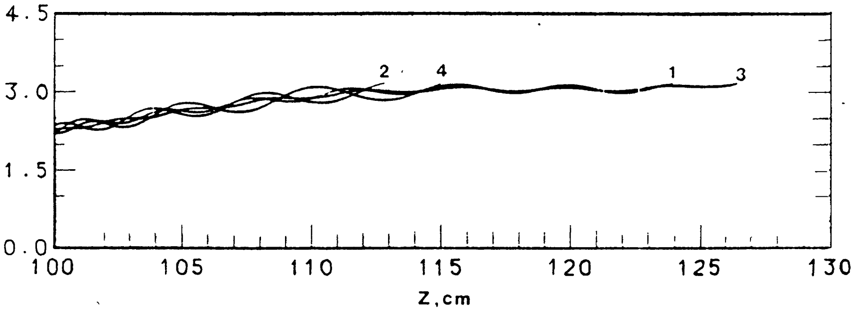

Fig. 5 - Longitudinal view of electron trajectories in the collector region

5. OUTPUT WINDOW

To evaluate quantitavely the properties of a dielectric window, consider the expression for the power loss density [2]:

$$p_d \cong 3.34\ (P_0/\lambda\ R_w)\ (p + 1/4)\ \varepsilon_r \tan\delta$$

where P_0 is power transferred by a TE_{0p} mode propagation in a uniform waveguide with radius R_w; λ is the wavelength in the free space; ε_r and $\tan\delta$ are, respectively, the dielectric constant and the loss tangent of ceramic material. Inserting the design values of the 35 GHz gyrotron [p = 2 (TE_{02}), λ = 0.857 cm, R_w = 3.18 cm, P_0 = 100 kW, and considering the typical value ε_r tan δ 1,0 x 10^{-2} and a thermal capacity C = 3,5 J/cm³ °C for an alumina of 96% purity], into eq. above, the temperature rise $\Theta = p_d \Delta t/C$ is about 5°C for a pulse width Δt = 20 ms.

Since the 100 kW pulse should be repeated for every 50 s, and assuming the disc thickness of 0.43 cm, that corresponds to a third of wavelenght of radiation in dielectric, the average power loss is less than 5 W. Under this condition the heat produced inside the dielectric disc is easily transferred by conduction to the cylindrical wall.

6. TRIGGER ELECTRICAL CIRCUIT AND HIGH VACUUM SYSTEM

The trigger electrical circuit consists basically of a series regulator circuit which regulates the output voltage level and controls the pulse width [3]. Besides that, a protection circuit protects both tubes, regulator and gyrotron, against faults in the system.

The vacuum system uses a diffusion pump with nitrogen trap and titanium sublimator in order to produce a vacuum about 10^{-8} Torr. A high vacuum is necessary to optimize the electron gun operation.

7. CONCLUSION

The construction of a gyrotron is a very complex task and many relevant technologies had to be developed to complete it. Some of the subsystems under construction (high voltage switching, regulator and protection circuits [3], high voltage and high current thermoionic electron guns, and magnetic coils for the generation of intense fields with high spatial and temporal uniformity) require the development of ceramic-to metal sealing, electroforming [4] and microwave diagnostic techniques [5], and techniques for the manufacturing of porous matrix cathodes [6].

Table 1 shows the main characteristics of the device that is being developed.

Table 1 - Design parameters for th 25GHz gyrotron

Maximum output power (kW)	100
Operating frequency (GHz)	35.0
Nominal mode	TE_{021}
Beam voltage (kV)	50.0
Gun anode voltage (kV)	24.5
Laminar beam current (A)	5.0
Current density (A/cm^2)	4.0
Cavity magnetic induction (kG)	13.2
Cathode magnetic induction (kG)	1.05
Beam radius at cavity input (cm)	0.698
Electronic efficiency (%)	40
Pulse duration (ms)	20
Duty cycle (%)	1.2

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