94GHz Second-Harmonic Gyrotron with Complex Cavity

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Abstract- **Systematic theoretical and experimental study on 94GHz second-harmonic gyrotron high frequency system is presented in this paper. A gradual transitions complex cavity is employed in the gyrotrons. Self-consistent field nonlinear theoretical investigation and numerical simulation in detail for interaction between electron beam and RF fields in complex cavities are given. At the same time, gyrotron's inner TE_{03}-TE_{02}-TE_{01} mode converter and collectors are designed with compact bulk and high efficiency, and the burned patterns measured at the ends of converter are produced by the gyrotron.**

I. Introduction

Gyrotron are capable of producing high-power millimeter wave radiation and have emerged as the premier source of high-power millimeter waves[1,2]. High-power gyrotrons have already been used successfully in electron cyclotron resonance heating of fusion plasmas. Gyrotrons have many other potential applications, including ceramic sintering in millimeter wave ovens, high density communications, and high-resolution radar within the atmospheric windows of 35, 94 and 140GHz. The paper is organized as a nonlinear theoretical investigation and numerical simulation for the interaction between the electron beam and RF fields in a complex cavity are given.

II. Fundamental Equations and Theory of Mode Converters

The complex cavity with gradual transition has the

$$
\begin{aligned}
\frac{d^2 f_{mp}^{(i)}}{dz^2} &= \left(\gamma_{mp}^{(i)}\right)^2 f_{mp}^{(i)} + Z_{mp}^{(i)}\gamma_{mp}^{(i)}\iint_s \mathbf{J}_t(\mathbf{r})\cdot\mathbf{e}_{mp}^{(i)*}dS \\
&+\frac{j}{\omega\varepsilon}\frac{d}{dz}\left[\iint_s \nabla_t J_z\cdot\mathbf{e}_{mp}^{(i)*}dS\right]+\frac{d(\ln Z_{mp}^{(i)}\gamma_{mp}^{(i)})}{dz} \\
&\cdot\left\{\frac{df_{mp}^{(i)}}{dz}-\frac{1}{R}\frac{dR}{dz}\sum_{i'}\sum_{mp'} f_{mp'}^{(i')}C_{(mp)(mp')}^{(i)(i')}-\frac{j}{\omega\varepsilon}\iint_s \nabla_t J_z\cdot\mathbf{e}_{mp}^{(i)*}dS\right\} \\
&+Z_{mp}^{(i)}\gamma_{mp}^{(i)}\cdot\frac{1}{R}\frac{dR}{dz}\sum_{i=1}^{2}\sum_{mp'}\frac{C_{(mp')(mp)}^{(i')(i)}}{Z_{mp'}^{(i')}\gamma_{mp'}^{(i')}} \\
&\left\{-\frac{df_{mp'}^{(i')}}{dz}+\frac{j}{\omega\varepsilon}\iint_s \nabla_t J_z\cdot\mathbf{e}_{mp}^{(i)*}dS+\frac{1}{R}\frac{dR}{dZ}\cdot\sum_{i''=1}^{2}\sum_{mp''} f_{mp''}^{(i'')}C_{(mp')(mp'')}^{(i')(i'')}\right\} \\
&+\frac{1}{R}\frac{dR}{dz}\sum_{i'=1}^{2}\sum_{mp'}\frac{df_{mp'}^{(i')}}{dz}C_{(mp)(mp')}^{(i)(i')} \\
&+\left[\frac{1}{R}\frac{d^2R}{dz^2}-\left(\frac{1}{R}\frac{dR}{dz}\right)^2\right]\sum_{i'=1}^{2}\sum_{mp'} f_{mp'}^{(i')}C_{(mp)(mp')}^{(i)(i')}
\end{aligned}
$$

advantage of overcoming mode competition and enhancing interaction efficiency. Start from general transmission line equation with an electron beam, the differential equations on $f_{mn}^{(i)}(z)$ is obtained[3]:

where $f_{mp}^{(i)}(z)$ is profile functions of the RF amplitudes, a is radius of waveguide, $Z_{mp}^{(i)}$ represents the wave impedance, $C_{(mp)(mp')}^{(i)(i')}$ is the coupling factor between mode mn' and mode mn, which could be obtained from paper.

III. Results of Numerical Calculation

Adopting the periodic perturbation of radius, the TE_{03}-TE_{02}-TE_{01} circular waveguide mode converter is optimized with input mode TE_{03} and frequency of 94GHz, radius of 9mm. Variable uptaper of sinusoidal curvature is used in waveguides outputs. Heavy considerations have been given to the influence of multimode factor, ohmic losses carried from metal wall, modes choice and phase rematch[4].

TE_{03}-TE_{02}, TE_{02}-TE_{01} inner mode converter and collectors of second-harmonic complex cavity Gyrotron have been designed, constructed and tested. A pulse output power of 110kW is obtained at a beam voltage of 60kV with beam current of 9A, operating mode TE_{02}-TE_{03}, average output power 2kW, magnetic field 1.67T with operating frequency 94GHz, corresponding to an efficiency of 20.4%. Burned patterns of TE_{01} mode measured at the ends of converter are produced by the gyrotron shows fig 1-6.

IV. Conclusions

3mm band second-harmonic complex cavity gyrotron operating on mode TE_{02}-TE_{03} and inner TE_{03}-TE_{02}-TE_{01} mode converter and collectors are designed with conversion efficiency 98.7%, the results have got the very good certification in Gyrotron test.

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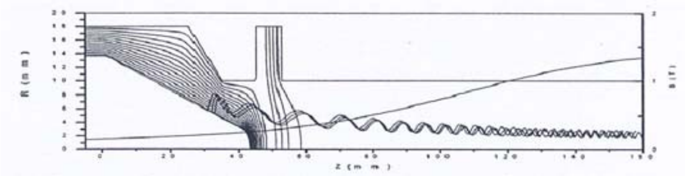

Fig.1 Track of electron beam in the MIG gun

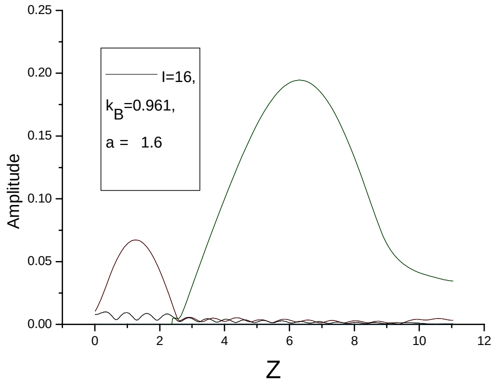

Fig.2 Axial field amplitude profile of each mode operating in the complex cavity

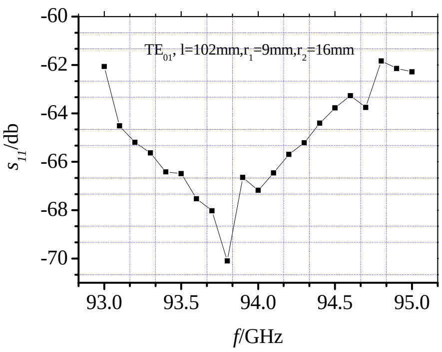

Fig.3 Results of waveguide tapers with sinusoidal curvature

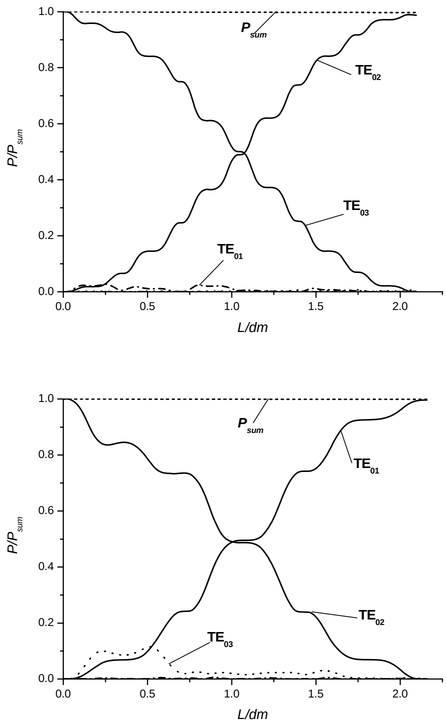

Fig.4 Fractional power of TE_{03}—TE_{02} and TE_{02}—TE_{01} distribution along mode converter

Fig.5 Burned patterns of TE_{01} mode measured at the ends of converter are produced by the gyrotron.

Fig.6 Photograph of 94GHz second-harmonic gyrotron with complex cavity

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