SHEET BEAM GYROTRON – A NOVEL CONCEPT

OM RANJAN and A K SINHA
Gyrotron Laboratory, Microwave Tubes Area
Central Electronics Engineering Research Institute-CSIR, Pilani-333031, Rajasthan, India
E-mail : om5886@gmail.com , aksinha876@yahoo.com

Abstract— **The Gaussian RF beam of a gyrotron can be applied as an input for the interaction with a high-current sheet electron beam drifting along an external magnetic field, with the aim of generating an even higher RF power and without the need for the feedback from the walls of any cavity or the resonator.**

In this paper, we have analyzed sheet beam gyrotron. This novel concept of sheet beam gyrotron is applied to a typical gyrotron of 170 GHz frequency and 2 MW output power. This paper also includes some typical results related to parallel (axial) component of normalized momentum and relativistic factor.

I. INTRODUCTION

The development of the electron cyclotron maser (ECM) devices and particularly the gyrotron as dominant high-power sources in the microwave spectrum has been primarily motivated by the high power demands at very high frequency. Gyrotron oscillators employ a weakly relativistic electron beam propagating along a strong magnetostatic field in a microwave resonator. Part of the kinetic energy of the electrons is converted to electromagnetic (EM) energy and thus produces an efficiently coherent EM radiation of up to about 1–3MW, in the range of 100–200 GHz. However, despite these achievements, at present, an output CW power of more than about 2 MW does not seem feasible at the desired frequency, primarily because the required large cavity size is not compatible with the single-mode operation in a conventional gyrotron.

A sheet beam gyrotron in which a large volume is made available to the interaction (hence, keeping open the prospects for high output power), while at the same time, mode competition does not seem to be an issue. More specifically, the basic idea is to amplify the RF beam produced by a high-power gyrotron propagating in free space, via its interaction with a sheet electron beam that propagates along a magnetostatic field (Fig. 1), which intersects the RF beam at a right angle. The perturbed electron motion excites an additional radiation field which is constructively added to the initial one, producing a substantial power gain. The total EM radiation is then waveguided to the application area while the electrons lay down part of their remaining energy on a (multistage) depressed collector. The width of the sheet beam could be quite large, equal to a large multiple of the radiation wavelength, so that the current density could remain low to avoid any significant space-charge effects, while the interaction volume is large, as already mentioned. At the same time, the frequency of the wave is controlled only by the parameters of the source gyrotron and not by any (anyhow, nonexistent) resonator around the interaction region; hence, mode competition does not occur.

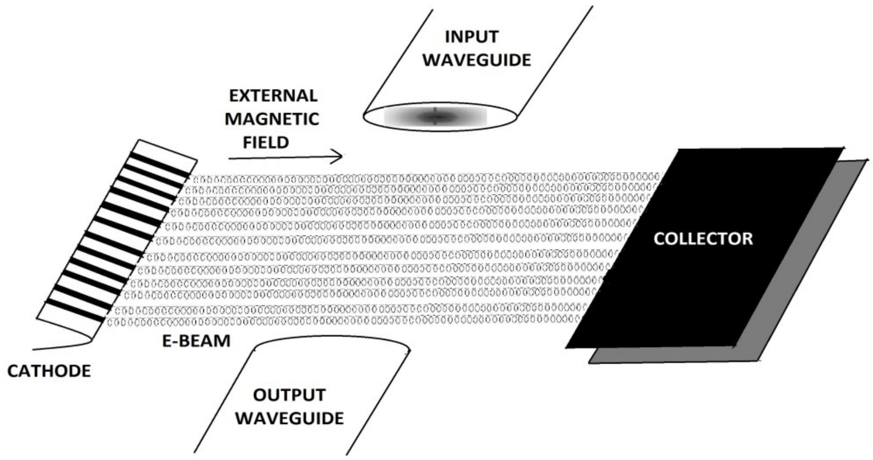

Fig. 1 : Proposed configuration of sheet beam gyrotron

The configuration studied in this paper shares most of the advantageous features of quasi-optical gyrotron (QOG), but most importantly, it avoids some of its important drawbacks :

1) There is no need for a cavity or resonator, as single-mode operation is expected, at the frequency provided by the gyrotron, and the sheet beam can be introduced at any convenient position along the output line of a gyrotron, possibly far away from the gyrotron.
2) The ECM interaction occurs with a propagating rather than standing wave, which potentially leads to a better coupling between the electrons and the field, since zero field nodes are not present.
3) The established Gaussian RF beam provided by a conventional high-power gyrotron is well formed, allowing the interaction to proceed immediately at the large signal nonlinear regime that is characterized by high efficiency, with no mode competition problems.
4) For the electrons to interact with the radiation fields at practically their maximum amplitude, the thickness of the sheet e-beam is limited by the size of the waist of the Gaussian, which is typically several times larger than the transverse wavelength (the limiting factor for beam thickness in the conventional hollow-beam gyrotrons).
5) Since the sheet e-beam simply amplifies an existing well established radiation beam, no threshold represented by the start-up current is applicable; a low-current e-beam would still amplify the RF beam, albeit by a much smaller amount.

Anastassiou *et. al.*[1]-[2] have proposed and studied sheet beam gyrotron concept. In this paper, steps to get some initial results in sheet beam gyrotron for 170 GHz, 2 MW have been discussed and presented.

II. Electron Trajectories and Radiation Field of Gyrating Electrons

The field components of the RF beam from the gyrotron, have the typical Gaussian form

$$\mathbf{E}(\mathbf{r},t) = E_0(\mathbf{r}) \exp(-r^2/r_0^2) \sin(kz-\omega t)\ \mathrm{i}_y\ , \quad \mathbf{B} = \mathbf{i}_z \times \mathbf{E}/c \qquad (1)$$

and the electron beam propagates gyrating around the field lines of a magnetostatic field $\mathbf{B}(\mathbf{r}) = B_0\, \mathbf{i}_x/\mu_0$. The interaction is governed by the Lorentz force

$$\mathbf{F} = d\mathbf{p}/dt = -e[\mathbf{E} + \mathbf{v}\times(\mathbf{B}+\mathbf{B_0})] \qquad (2)$$

the two pairs of equations (for the electrons affected by the radiation and for the electromagnetic field excited by the electrons) formally constitute a self-consistent system of equations numerically calculated using an iterative procedure in which the radiated fields (or, the electron motion) can be obtained using the latest approximation for the electron properties.

III. Results And Discussion

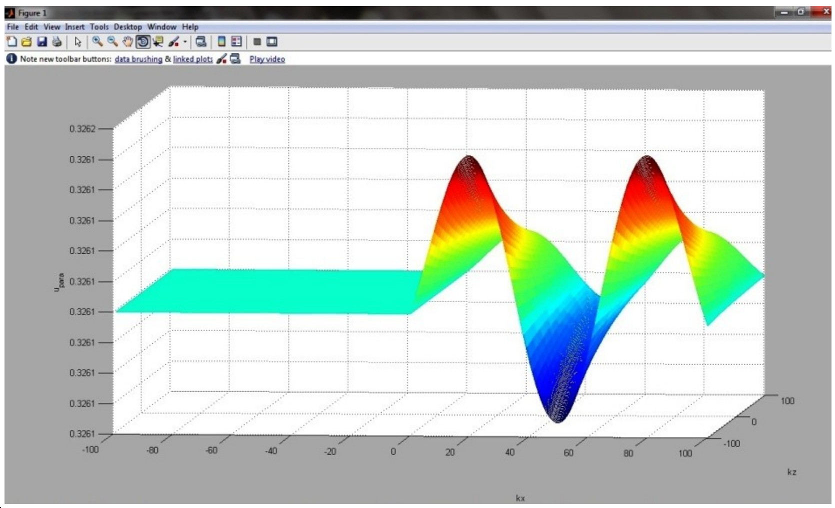

Fig. 2 : Variation of parallel normalized momentum

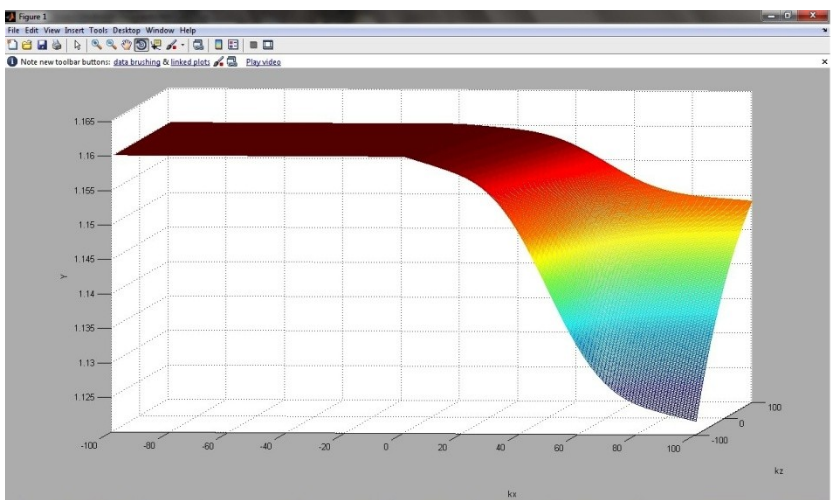

Fig. 3 : Variation of relativistic factor

The equations discussed above are solved numerically using a fourth-order Runge–Kutta integration algorithm. Introducing an electron beam of I = 100A accelerated by a voltage of 80 kV (meaning γ_0 =1.16) under the initial conditions α = 1.5, Fig.2 depicts the evolution of the mean parallel momentum while Fig.3 depicts the variation of γ along x-axis as well as z-axis. The decrease in γ shows the decrease in the kinetic energy of the electrons. This amount of the energy is equal to the energy going to the RF beam and the losses occur in the interaction region.

To get the results presented in Fig. (2) and (3) from eqs. (1)-(2), references [3][4] are important to be studied.

.

IV. Conclusion

Higher current having low current density and high aspect ratio can be used to amplify the RF beam. The frequency of operation is found to be independent of structure dimension. The decrease in relativistic factor γ simply means the decrease in kinetic energy of the electron beam. The RF beam receives this energy and gets amplified.

Attempts have been successfully initiated at CEERI to do research towards sheet beam gyrotron – a novel concept, to achieve more RF power with reduced complexity.

Acknowledgement

The authors are grateful to the Director, CEERI, Pilani, for permission to publish this paper. Thanks are due to Dr. SN Joshi for his continuous support and encouragement. The authors are also grateful to Prof. B N Basu and Prof. P K Jain for their valuable suggestions. Lastly the gyrotron team members are also being thanked for their co-operation.

Refferences

[1] G. Anastassiou, J. L. Vomvoridis, "Post-Amplification of a Gyrotron RF Beam by a Sheet Electron Beam", *IEEE Transactions On Plasma Science,* 38(6):1208-1218, 2010.

[2] G. Anastassiou, J. L. Vomvoridis, "Post-Amplification of a Gyrotron RF Beam by a Sheet Electron Beam", The Joint 32nd Int. Conf. on IRMMW and 15th Int. Conf. On THz Electronics, 2-7 Sept. 2007.

[3] J. D. Jackson, *Classical Electrodynamics*, 3rd ed. New York: Wiley, ch. 14.

[4] A. S. Gilmour, Jr. Klystrons, Traveling Wave Tubes, Magnetrons, Crossed-Field Amplifiers and Gyrotrons, Artech House, ch. 21