

ANNEX I

Post-amplification of a Gaussian rf beam from a gyrotron via interaction with a sheet electron beam: Self-consistent radiation pattern*

G. E. Anastassiou and J. L. Vomvoridis

School of Electrical and Computer Engineering, National Technical University of Athens,
Zographou 15773, Athens, Greece

INTRODUCTION

The availability of high power gyrotrons gives the possibility to amplify the rf output beam by having it interact with a sheet electron beam, which travels along a magnetostatic field and intersects the propagating Gaussian beam at a right angle. This arrangement is similar to the concept of the quasi-optical gyrotron, shares most of its advantageous features, i.e. high beam power, large volume for the e-beam, and in addition and of more importance, it has significant beneficial differences: There is no need for a resonator (and no ohmic loading), single mode operation is assured (at the frequency of the conventional gyrotron), and can admit a large amount of current at relatively low current density. The total field generated by this interaction has been calculated using a self-consistent scheme based on successive iterations, that is, at each step the properties of the electron beam are calculated under the action of the radiation field from the previous iteration, until convergence is finally achieved. Consequently, a high power gyrotron would provide the initial rf beam and the quasi-optical concept would be introduced as second stage, in order to amplify the rf power to the levels required for ECRH in a fusion reactor.

GENERALISED ELECTRON TRAJECTORIES AND RADIATION FIELD OF GYRATING ELECTRONS

The application of the self-consistent scheme on the plane of the e-beam, is introduced in our calculations in order to calculate the electrons trajectories, as they are perturbed by the radiation fields, which in turn is consistent with what that the electron motion excites. A relatively small number of iterations (depending on the parameters of the simulation) is sufficient for convergence to be accomplished. Then, being in a steady state condition, the time dependence can be omitted from our calculations, and we can work with the phasor representation of the EM field [1].

Furthermore, because of the previous iterative scheme, the equations of motion standing for the electron trajectories had to be reconsidered (mostly the part that represents the exciting field term) in order to handle adequately not only the initial Gaussian field distribution of the first step but also any radiation field that may develop during the interaction. The only limitation that underlies our approach is the (reasonable) assumption that a) we always deal with radiation fields that have the general form of the plane wave equation $\sim \sin(\mathbf{k}\cdot\mathbf{r}-\omega t)$ and b) the electron motion is dominated by the gyro-motion around the magnetostatic field lines. Hence, the equations of motion are of the form:

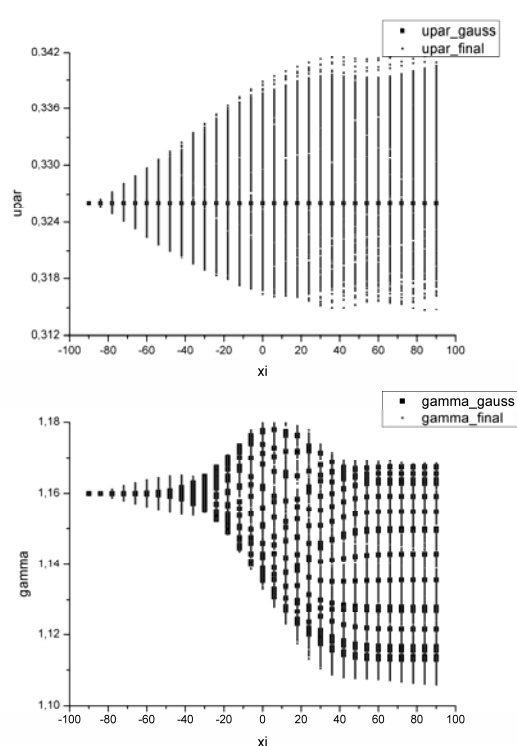


Fig. 1: The parallel velocity $upar = f(\zeta)$ and the gamma factor $\gamma = f(\zeta)$ of the electrons, at the first step (black dots) and at the last step (grey dots) of the self-consistent iterations.

* Work performed in co-operation with FZK (Karlsruhe) and CRPP (Lausanne). Constructive contribution and private discussions with Dr. I. Pagonakis and Prof. E. Glytys are kindly acknowledged.

$$\frac{du_{\parallel}}{d\xi} = -\frac{u_{\perp}}{2u_{\parallel}} \left[\beta_{z0} \cos(A - \varphi_{b_z}) + \beta_{y0} \sin(A - \varphi_{b_y}) \right]$$

$$\frac{d\gamma}{d\xi} = -\frac{u_{\perp}}{2u_{\parallel}} \left[\varepsilon_{y0} \cos(A - \varphi_{\varepsilon_y}) - \varepsilon_{z0} \sin(A - \varphi_{\varepsilon_z}) \right]$$

where ε , β is respectively the normalised electric and magnetic field amplitude, and the arguments of the trigonometric functions are numerical values and stand for the phase difference between the components of the field phasor. (For simplicity, only the equations related to the quantities in Fig. 1 are exhibited.)

After self-consistency is achieved, the radiation fields are calculated above as well as below the plane of the e-beam according to the theory of radiation generation by moving charges (as it is already demonstrated with more details in [1]), the 3D radiation pattern is determined, and the total field power is calculated, integrated in all directions.

NUMERICAL IMPLEMENTATION

Although the existing Matlab code was completed successfully, a long execution time was unavoidable, even for simulations with reduced demand. For this reason we undertook to replace it by a more powerful code, in a lower-level programming language like C++. Our efforts were focused on that goal and the new code is now operational, even though it is still under continuous development and improvement. Its results have been practically identical with these obtained by the corresponding Matlab code, but nevertheless a comparison with a numerical code that calculates the field components of an analytically prescribed excitation is under investigation. Furthermore, the parallelisation of the C++ code is under consideration, in order to increase the numerical efficiency of the code by reducing the execution time, and to take into account more realistic and time-consuming simulations.

In the present form, our code calculates both the electron trajectories and the radiation on the plane of the e-beam, at every step, until steady state condition is reached. At this point, using the last step information, the radiation field components are identified and calculated above and below the e-beam plane, resulting in the 3D radiation field pattern of the interaction. Sample results for the case of a field produced by an 80 kV, 100 A electron beam [2], have revealed that the dominant components of the initial beam (E_y , B_x) have largely retained their Gaussian shape (Fig. 2), while all other components represent noise, suggesting that a substantial power gain may occur.

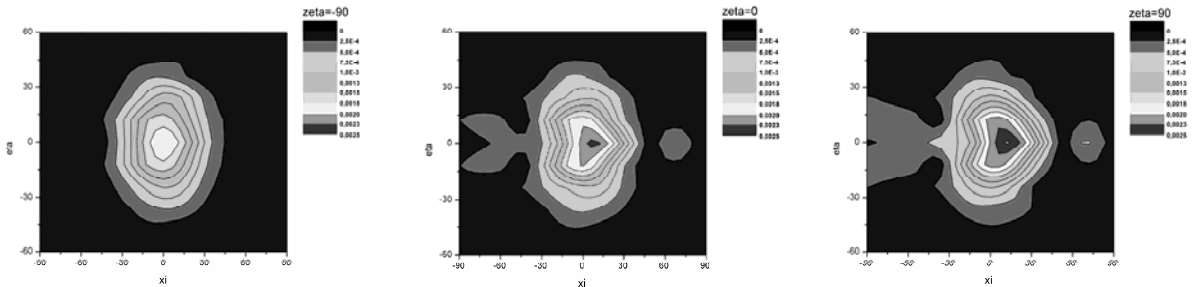


Fig. 2: Amplitude cross-section of the E_y component of the radiation field, along the propagation axis of the rf beam. It is evident that a significant amplification takes place along the axis, and at the same time, the cross-section is being elongated and a side radiation-lobe is arising.

REFERENCES

- [1] G. E. Anastassiou and J. L. Vomvroidis, *Annex I in Fusion Project, Association EURATOM-Hellenic Republic, Annual Report 2005*.
- [2] G. E. Anastassiou and J. L. Vomvroidis, *Annex I in Fusion Project, Association EURATOM-Hellenic Republic, Annual Report 2004*.