P1-4: Comparison of Plasma Frequency Reduction Factors Simulated *via* 1D Time Domain Lagrangian Code and Expressions in the Literature

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Abstract: *In this work, we present a comparison between plasma reduction factors for the case of a pencil e-beam inside a hollow metallic pipe. The values under comparison were obtained via analytic expressions given in the literature and the result of a 1D large signal time domain code. The main distinctive feature of this analysis is the additional consideration of dc space charge forces, since the actual electrostatic force among particles is computed, instead of making the assumption of a neutralizer background. In this way, the propagation of space charge waves can be simulated and the reduced plasma wavelength can be obtained. Simulated results were compared to three others obtained via formulae in the literature. A discrepancy of 1.6~5.4% for a klystron example and 0.7~2.2% for a TWT example, between analytic and simulated results were observed.*

Keywords: large signal simulation; lagrangian code; e-beam disk model; space charge simulation.

Introduction

The preliminary steps in the development of a vacuum electronic device, such as traveling-wave tubes (TWT) and klystron amplifiers, require simple and fast design tools in order to obtain the initial manufacturing parameters. Several codes for TWT and klystrons were developed using the simple and fast lagrangian disk model for the electron beam. In the most of them, dc space charge effects are neglected by means of an assumption that the e-beam is surrounded by a background of neutralizer ions. The ac space charge electric field is commonly computed via Gauss law, where the electric field is weighted by a space charge reduction factor R_{sc}, which accounts for the effects of the structure around the e-beam. The space charge reduction factor can be calculated for a couple of simple beam and surrounding structure geometries [1][2]. The code Christine 1D [3] presents an improved formula to calculate the space charge reduction factor for an e-beam surrounded by a sheath helix, which in turn, is surrounded by a metallic pipe with vanes and dielectric supports. This correction is claimed to be of order of few percent or less for typical helix TWT parameters [1 - section 4.2.6]. Besides some developed 1D codes, specially Christine 1D, have been validated against experimental results, we believe that there is some room for improvements while keeping the code fast and simple enough to be quickly used in the preliminary device design steps. Our purpose is to remove the assumption of the neutralizer background and compute the actual (dc+ac) force among charged particles inside a particular structure (pipe, +tape helix, +vanes, +dielectric supports, +etc). Therefore, the calculation of the space charge reduction factor is no longer necessary, because all the information about the surrounding structure is contained in the dc force among particles. By the way, the space charge reduction factor may be one of the results extracted from the simulation result. This can be done "measuring" the reduced plasma wave-length in the interference pattern of the fast and slow space charge waves excited on the e-beam medium [4] or in the maximum of the first harmonic component of the e-beam current.

In the next section, we briefly describe the e-beam model and, after that, we present a numerical example, comparing the space charge reduction factor obtained by well known literature formulae and by the present code.

The e-beam disk model

The discrete equations system that describes the 1D motion of N_d disks, each one with electric charge q, is simply

$$\mathit{for}\ j = 1 : N_d$$
$$\begin{cases} \dfrac{d}{dt} z_j(t) = u_j(t) \\ \dfrac{d}{dt} u_j(t) = \dfrac{1}{m} \left\{ \displaystyle\sum_{i=1}^{N_d} F_{\mathrm{sc}}\left(z_i(t) - z_j(t)\right) \right. \\ \qquad\qquad \left. + F_{\mathrm{mod}}\left(z_j(t) - z_{\mathrm{mod}}, t\right) \right\} \end{cases}, \quad (1)$$

where $F_{sc}(\Delta z)$ is the electrostatic force between two charged disks inside the particular structure and $F_{\mathrm{mod}}(z,t)$ is the force that the electric field associated to a modulator signal exerts on charged disks. Depending on the type of device, i.e., TWT or klystron, $F_{\mathrm{mod}}(z,t)$ is evaluated in different ways, e.g., by means of a traveling electric field in a TWT slow-wave structure or by means of an evanescent axial electric field near a cavity gap of a klystron. z_{mod} is the axial position where the modulation occurs.

Numerical example

For a numerical example we use the following parameters of a klystron and for a TWT, as well.

Table I - klystron parameters

klystron	
frequency (GHz)	1.849
cathode voltage (V)	6000
dc current (A)	0.525
beam radius (mm)	2.92
drift tube radius (mm)	3.40

Table II - TWT parameters

TWT	
frequency (GHz)	13.75
cathode voltage (V)	6900
dc current (A)	0.2
beam radius (mm)	0.500
helix radius (mm)	1.0
helix width/pitch ratio	0.5
guide/helix radius ratio	1.85
number of supports	3.0

The $F_{sc}(\Delta z)$ component of the total force on the particles was computed in two distinctive ways. The first way was using an analytic expression for charged disks of radius b inside a metallic pipe of radius $a > b$. In the other way, a 3D electrostatic solver was used to compute the force between two discs as a function of its axial separation. In this case, the structures surrounding the pair of disks were:

1. a metallic pipe of radius $a > b$;
2. add a tape helix of radius between a and b (table II);
3. add 3 BeO dielectric support rods to hold the helix inside the pipe.

Interestingly, the results for cases 2 and 3 are very close to that in the case 1, which in turn, agrees very well with the analytical case, as presented in Figure 1. Therefore, only the analytical expression was used in this work.

After run the code, the reduced plasma wavelength λ_q is obtained by "measuring" the $\lambda_q/4$ (klystron) and $\lambda_q/2$ (TWT) point in the result for the harmonic current in the e-beam, as Figure 2 illustrates. The results for the simulated R_{sc} are compared to the calculated ones via literature formula [1][2][3] in Table III.

Table III - Space charge reduction factor comparison

example	formula Ref [1]	formula Ref [2]	formula Ref [3]	present work	discrepancy related to Ref [1]	discrepancy related to Ref [2]	discrepancy related to Ref [3]
klystron	0.335	0.312	0.3279	0.317	5.4%	1.6%	3.3%
TWT	0.500	0.493	0.507	0.496	0.8%	0.7%	2.2%

Conclusion

In this work, we presented a comparison between space charge reduction factors calculated via literature expressions and via simulation with a 1D time domain klystron-TWT code that considers the dc+ac space charge forces. Our results present little discrepancy related to main formula results.

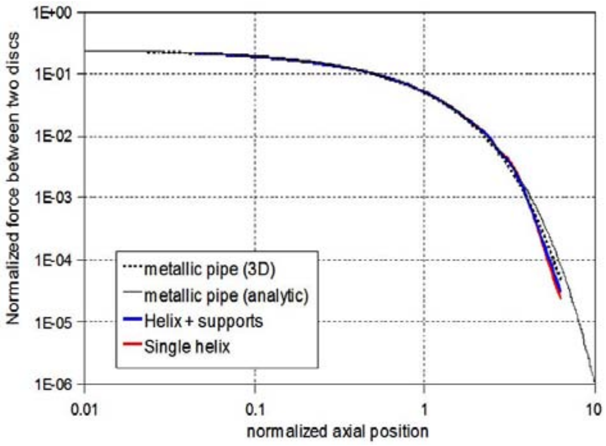

Figure 1 - Force between a pair of charged disks as a function of its distance for 3 different surrounding structures.

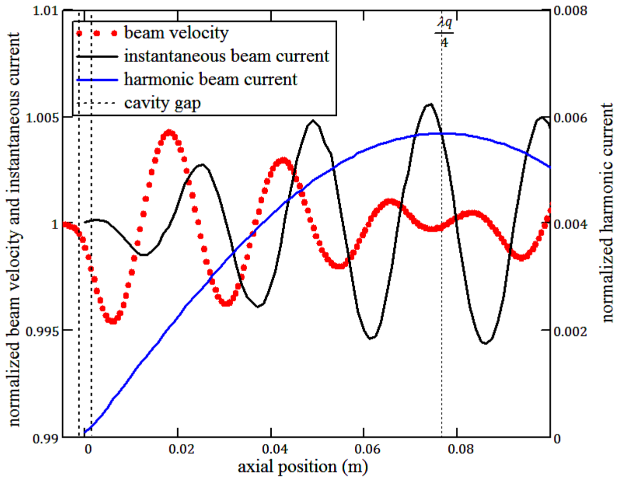

Figure 2 - Phase space, instantaneous and harmonic beam current for the klystron example. The $\lambda_q/4$ point is indicated in the plot. Axial position is given in meters.

References

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