P1-5: Study of Non-Relativistic Klystron Amplifier Using a 1D Time Domain Lagrangian Code Considering Both AC and DC Space Charge Effects

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Abstract: *In this work, we present a simple and fast 1D time domain code for the simulation of a nonrelativistic multi-cavity klystron. The main features of this code are the consideration of both ac and dc space charge forces and a progressive convergence of the voltage in each interaction gap. The amplitude of the gap voltage is weighted by a factor depending on the gap geometry. A comparison between simulated and experimental data available in the literature is presented in order to validate the code.*

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

Introduction

The preliminary steps in the development of a vacuum electronic device, such as klystrons amplifiers, require simple and fast design tools in order to obtain the initial manufacturing parameters. Several codes for klystrons were developed using the simple and fast lagrangian disk model for the electron beam, e.g., [1][2][3]. In some 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.

Besides some of the cited 1D codes have been extensively used in the design of klystrons and are available for the community, we believe that there is some room for improvements while keeping the code still 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 computing the actual (dc+ac) force among charged particles inside the drift tube.

In the next section, we briefly describe the e-beam model and, after that, we present a numerical example, comparing the experimental $P_{out}(P_{in})$ data available in the literature with simulated ones.

The klystron 1D time-domain model

Our 1D time-domain klystron code is based on the well-known disk-beam model. The disks are modulated in velocity by the interaction gap field and the harmonic current is used to compute the voltage induced in the other interaction gaps. The equations system that describes the model, for an e-beam divided in N_d disks, is basically

$$for\ j = 1 : N_d$$
$$\begin{cases} \dfrac{d}{dt} z_j(t) = u_j(t) \\ \dfrac{d}{dt} u_j(t) = \dfrac{1}{m}\left\{ \displaystyle\sum_{i=1}^{N_d} F_{\text{sc}}\left(z_i(t) - z_j(t)\right) + \sum_{cav=1}^{Ncav} F_{\text{mod}}\left(z_j, t, cav\right) \right\} \end{cases} ,(1)$$

where $F_{sc}(\Delta z)$ is the electrostatic force between two charged disks inside the drift tube and $F_{\text{mod}}(z_{cav}, t)$ is the force that the electric field associated to the modulator field on the axial position z_{cav} exerts on a charged disk. F_{mod} is given by

$$F_{\text{mod}}(z, t, cav) = R_{cav} V_{cav}(t) F_{cav}(z - z_{cav}), \qquad (2)$$

where $V_{cav}(t)$ is the time-varying voltage on the gap of the cav-th cavity, $F_{cav}(z - z_{cav})$ is a shape function for the force around the gap of the cav-th cavity. R_{cav} is a scale factor that reduces the overestimated analytic value of $V_{cav}(t)$ calculated for the analytic case, as shown in Fig. 1. The value of R_{cav} is highly dependent of the cavity geometry, but was shown to be ~0.8 for the present geometry. For a fine tuning, R_{cav} was set as 0.78.

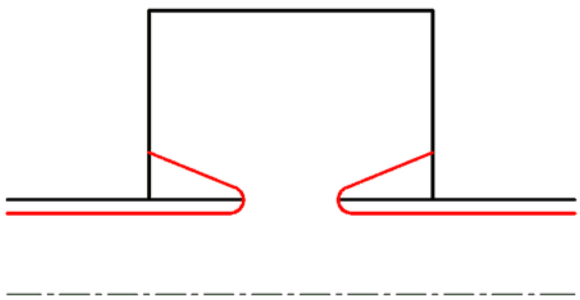

Figure 1 – Schematic axial section of a reentrant cavity showing the analytic model (black line) and an actual model (red line).

Numerical example

For a numerical example, we used the following parameters of a klystron, which AM-AM conversion data is available in the literature [4].

Table I - klystron parameters

klystron parameters	
frequency (GHz)	1.849
beam voltage (V)	6000
beam dc current (A)	0.6
beam radius (mm)	2.92
drift tube radius (mm)	3.40
number of cavities	4

Some cavities parameters are given in Table II. Cavities 1 and 4 were assumed to be the same as 2 and 3, since their data are not available in [4].

Table II - cavities parameters

cavity	1	2	3	4
gap width (m)	0.00292	0.00318	0.00318	0.00318
position (m)	0	0.0386	0.0772	0.1158
R/Q	100	100	100	100
Q	936	936	936	936

The phase-space, the instantaneous beam current and its first harmonic component are shown in Fig. 2 for the parameters in Table I.

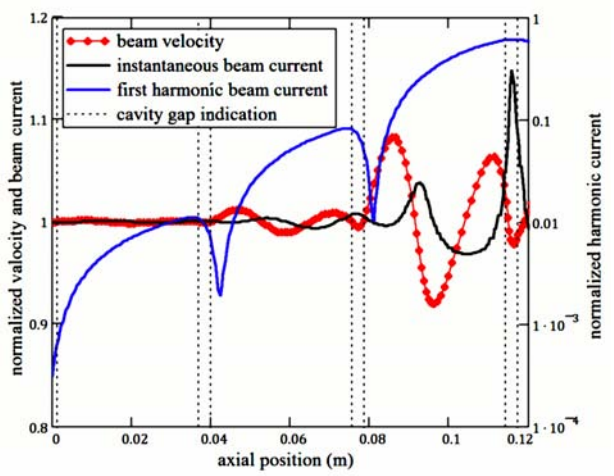

Figure 2 – Phase-space, instantaneous beam current and its first harmonic component for an input power of 10mW.

The simulated output power as a function of the input power is shown in Fig. 3. In general, a good agreement was achieved, though the saturated power was overestimated even considering the voltage gap weighting factor R_{cav}. The unknown data of the first and last cavities might also affect the result substantially.

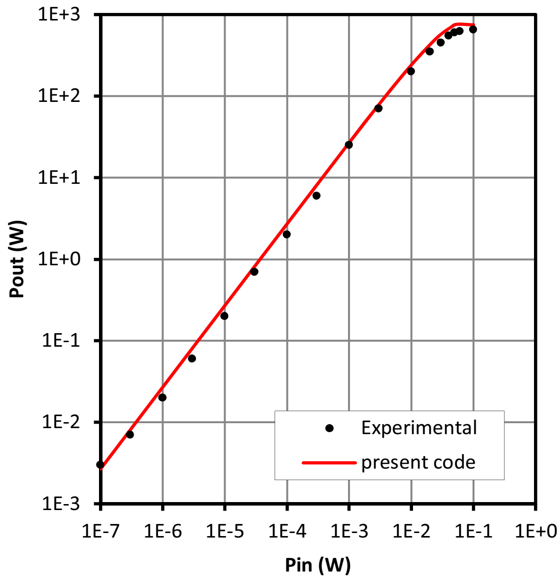

Figure 3 – Output power as a function of the input power for the device simulated. The points are experimental data [4].

Conclusion

In this paper, we presented AM-AM results of a multi-cavity klystron amplifier using a home-made 1D time domain large signal code. Klystron parameters and experimental data available in the literature were used to validate the code. Good agreement was found when the gap voltage was corrected by a factor depending on the gap geometry.

References

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