RELATIVISTIC KLYSTRON SIMULATIONS USING RKTW2D*

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Abstract

We are developing a two-dimensional, time-dependent computer code for the simulation of relativistic klystrons. We will discuss the main features of our code. We will also present an example simulation of a relativistic klystron with both a standing wave output cavity and a traveling wave output structure.

Introduction

Relativistic klystrons (RKs) that operate at high energy and with multiple extraction cavities are expected to be able to achieve high efficiencies. We are initiating experiments at the Advanced Test Accelerator at Lawrence Livermore National Laboratory to access this regime. The goal of this research is to develop induction linac-based RKs that produce around 1 GW of peak power for high gradient accelerator applications. We are developing a two-dimensional, time-dependent simulation code call RKTW2D to support this research.

Description of RKTW2D

RKTW2D follows a train of RF bunches, one at a time, through a klystron. The code has the following features:

1. 2D (r,z) azimuthally symmetric fields
2. self-consistent space charge (radial and longitudinal)
3. self-consistent beam-cavity interaction
4. treatment of standing wave (SW) cavities and traveling wave (TW) structures
5. time-dependent cavity excitation modelled using coupled circuit equations
6. cavity fields obtained from the RF cavity code SUPERFISH[1]

The basic equations used by RKTW2D are the single particle equations of motion and the coupled circuit equations governing cavity excitation. The single particle equations of motion are paraxial approximations to the Lorentz force equations using the longitudinal coordinate, z, as the independent variable:

$$\begin{aligned} \frac{dx}{dz} &= v_x/v_z, \\ \frac{dy}{dz} &= v_y/v_z, \\ \frac{d\psi}{dz} &= \omega/v_z, \\ \frac{dv_x}{dz} &= \frac{q}{\gamma m}\left(\vec{E}+\vec{v}\times\vec{B}\right)_x, \\ \frac{dv_y}{dz} &= \frac{q}{\gamma m}\left(\vec{E}+\vec{v}\times\vec{B}\right)_y, \\ \frac{d\gamma}{dz} &= \frac{q}{mc^2}E_z, \end{aligned} \tag{1}$$

where $\psi = \omega t$. Beam induced cavity excitation is based on a circuit equation (or coupled equations for TW structures). Assuming a single cavity mode is dominant, let the electric field in the n$^{\text{th}}$ cell of a traveling wave structure be given by

$$\vec{E}_n(\vec{r},t) = f_n\,\vec{\mathcal{E}}_n(\vec{r})\,e^{-i\omega t}, \tag{2}$$

where $\mathcal{E}_n$ denotes an eigenmode with eigenfrequency ω_n. Also, let ω denote the drive frequency of the klystron. Then it is possible to show that the excitations f_n are governed by the following coupled equations

$$\begin{aligned} &\ddot{f}_n + \left(\frac{\omega_n}{Q_n} - 2i\omega\right)\dot{f}_n + \left(\omega_n^2 - \omega^2 - \frac{i\omega\omega_n}{Q_n}\right)f_n \\ &-\left(K_n^{n-1}f_{n-1} + K_n^{n+1}f_{n+1}\right) = \frac{i\omega}{\epsilon_o}\int dV_n\,\vec{\mathcal{E}}_n^* \cdot \vec{J}_1, \end{aligned} \tag{3}$$

where Q_n denotes the quality factor of the n^{th} cell, K_n^{n-1} and K_n^{n+1} denote coupling of the cell n to cell $n-1$ and cell $n+1$, respectively, and $\vec{J}_1$ denotes the RF current associated with the beam.

Simulation of the MOK-2 Relativistic Klystron

The MOK-2 is a Multiple Output Klystron that consists of an input cavity, three gain cavities, a SW output cavity and a TW output structure.[2] The klystron operates at 11.4 GHz. It was developed as part of a joint LLNL/SLAC/LBL collaboration in RK research. The MOK-2 achieved a maximum output power of 330 MW (30 MW from the SW output cavity and 300 MW from the TW structure) using a 1.3 MeV, 600 amp beam. The RKTW2D results shown below are not meant to show a careful comparison of the code with experiment, but are simply illustrative of the code's capabilities. A precise comparison of RKTW2D with experiment is being carried out at this time as an ongoing part of our RK research effort.

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Figure 1 shows the input beam energy and current for the MOK-2 simulation. The 40 ns pulse has a 5 ns rise time , and 30 ns flat top, and a 5 ns fall time. The input cavity was driven at 1 kW and was assumed to have reached a steady state prior to the arrival of the beam. Figure 2 shows the voltage in the input cavity as a function of time and exhibits typical beam loading effects. Figure 3 shows the power produced by the SW cavity and Figure 4 shows the power produced by the TW structure. The SW cavity produces much less power because the RF current is lower there. Figure 5 shows that RF current as a function of distance along the klystron associated with an RF bucket 25 ns into the beam pulse. Though the SW output produces little power, it provides bunching so the RF current is large at the TW structure. The external magnetic field used in this simulation is shown in Figure 6; it is not the same as that used in the experiment but it does illustrate the code's ability to treat a variable magnetic field. Figure 7 shows the rms beam radius as a function of distance at 25 ns into the beam pulse.

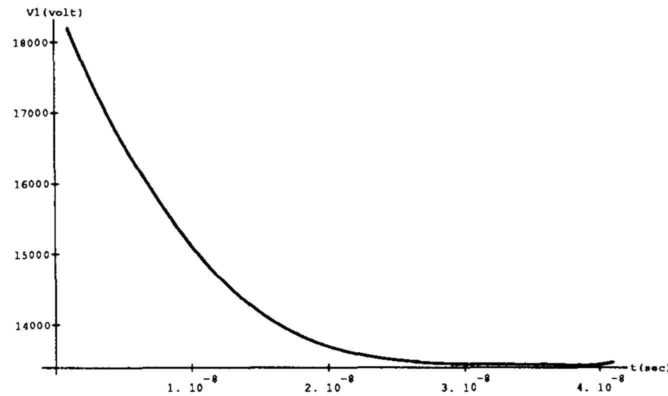

Figure 2 V_1 versus time

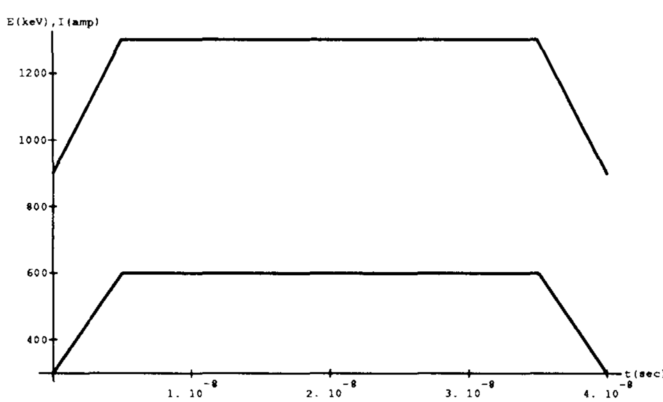

Figure 1 Beam energy (upper curve) and current (lower curve) versus time

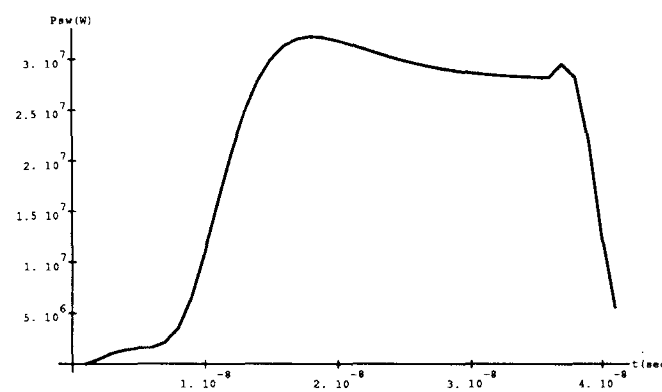

Figure 3 P_{sw} versus time

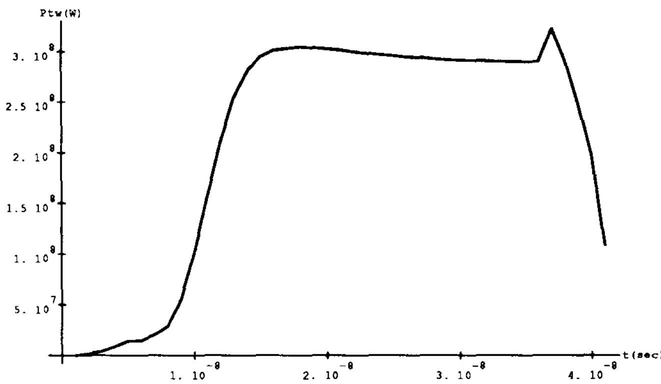

Figure 4 P_{tw} versus time

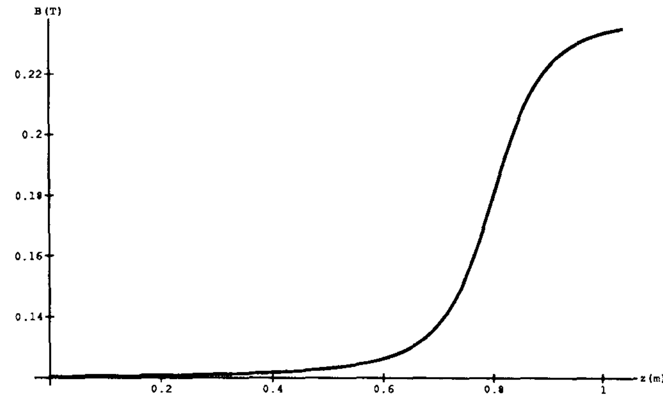

Figure 6 $B_z(r = 0)$ versus distance

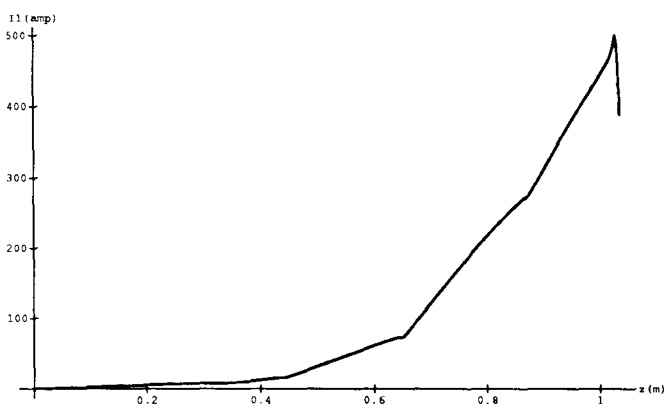

Figure 5 RF current versus distance (at t=25ns)

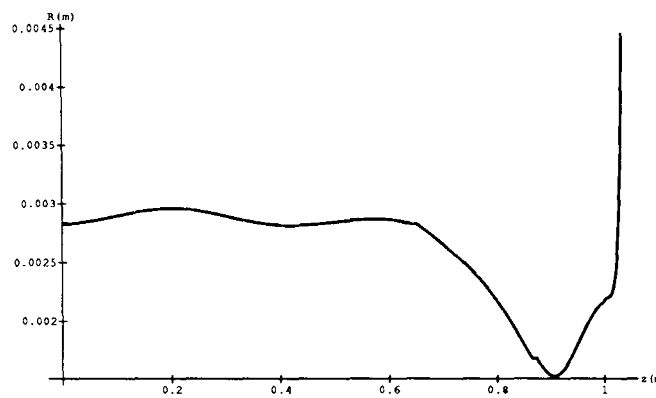

Figure 7 r_{rms} versus distance (at t=25ns)

Summary

We are developing a two-dimensional, time-dependent simulation code call RKTW2D to support relativistic klystron research at LLNL. Initial studies show that the code gives results that are similar to experimental results. We are carrying out careful comparisons of the code with experiment at this time.

References

1. K. Halbach and R. F. Holsinger, "SUPERFISH—A Computer Program for Evaluation of RF Cavities with Cylindrical Symmetry," Particle Accelerators **7**, pp. 213–222 (1976)

2. M. A. Allen et al., "Recent Progress in Relativistic Klystron Research," Particle Accelerators **30**, pp. 189–196 (1990)