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Retrofitting the 5045 Klystron for Higher Efficiency

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Abstract: *The 5045 klystron has been in production and accelerating particles at SLAC National Accelerator Laboratory for over 25 years [1]. Although the design has undergone some changes there are still significant opportunities for improvement in performance. Retrofitting the 5045 for higher efficiencies and a more mono-energetic spent beam profile is presented.*

Keywords: klystron; efficiency; second harmonic cavity;

Introduction

The 5045 klystron was introduced in the 1980's as the RF source for accelerating particles in the SLAC linac. After initial modifications to minimize infant mortalities the tube proved to be a very robust RF source with a cumulative MTBF of more than 50,000 high voltage hours [1]. The typical operating parameters are shown in Table 1.

Table 1. Typical 5045 Operating Parameters.

Frequency (GHz)	2.856
Beam Voltage (kV)	350
Perveance (μA/V$^{1.5}$)	2.0
Peak Output Power (MW)	65
Average Output Power (kW)	41
RF Pulse Width (μs)	3.5
Pulse Rep. Rate (Hz)	180
Gain (dB)	50
3dB Bandwidth (MHz)	20
Saturated Efficiency (%)	45
Cathode Loading (A/cm^2)	8

The 5045 klystron design has remained largely unchanged over the last couple decades. Although the design is robust, improvements could be made, such as using a pulsed depressed collector to improve efficiency [2]. Improvements in the circuit could also be made to increase the efficiency of the device and to produce a more mono-energetic beam which would be well suited for depressed collector design.

Spent Beam Analysis

In an effort to improve efficiency and produce a mono-energetic spent beam for depressed collector design, the interaction in the output cavity was studied. Starting with the assumption that the spent beam after the output cavity is mono-energetic it is possible to run the beam in reverse through the output cavity. Figure 1 shows the result of making this calculation. The Figure shows the energy each particle entering the output cavity must have as a function of the cavity's phase in order for all particles in the spent beam to exit at a constant energy (in this image, 60% of the DC beam energy).

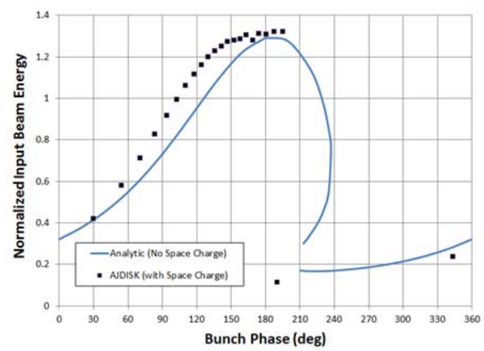

Figure 1. Optimal energy distribution in a bunch to produce a mono-energetic spent beam assuming no space charge versus cavity phase.

Calculating the desired position and velocity of the particles entering the output cavity becomes more difficult when space charge is included. To facilitate this calculation, with space charge, the 1D klystron code AJDISK was modified to run with time reversed. The top image in Figure 2 shows the velocity distribution for the first 5 cavities in the 5045 starting with a mono-energetic DC beam energy on the left. The result of this simulation is exported after the 5th cavity and run backwards with time reversed. In the lower image the beam propagates from right to left starting with the 5th cavity. The figure confirms that particle velocity and position are consistent when time is reversed.

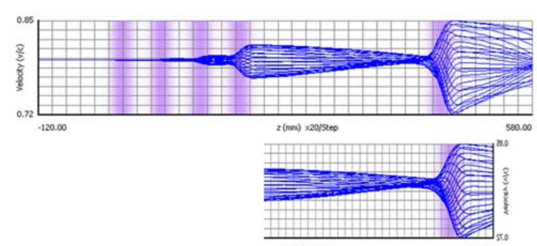

Figure 2. Velocity as a Function of Distance when the Beam is Run Forward in Time (top) and in Reverse (bottom).

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The square points in Figure 2 show the result of running a mono-energetic bunch (30% of a wavelength long) in reverse through the output cavity, with space charge included. The behavior is similar to that of the case without space charge. It was concluded that matching the shape of the desired energy spread at the entrance to the output cavity was non-trivial. Therefore the goal of achieving a high efficiency mono-energetic spent beam is to produce as tight a bunch as possible so that the energy spread only has to be matched over a narrow phase angle. The second goal is to produce a continuous energy spread, meaning that the number of particles that overtake each other should be minimized. It is interesting to note that achieving these goals is easier for low perveance klystrons where it is easier to form a tight bunch and for output cavities with high coupling coefficients where the beam can be slowed quickly without fighting space charge forces over a long distance.

High Efficiency Design

Achieving higher klystron efficiencies is outlined in [3] and [4]. These principles have been applied to the 5045 to achieve a more efficient design. An outline of the original 5045 is shown in Figure 3. Complete modification of the circuit is being considered but it is preferred to use the original design with cavities added to the long drift space between the 4th and 5th cavities. It is also desirable to fix the circuit length so that the existing solenoid can be used.

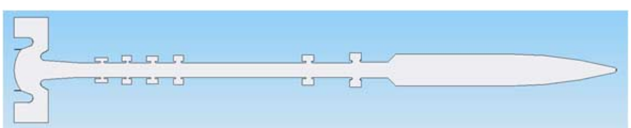

Figure 3. Existing 5045 Gun, Circuit and Collector Vacuum Envelope.

Figure 4 shows the effect of adding cavities in the drift section of the 5045. In this case the efficiency was improved from ~44% to 60%+ which is a considerable improvement for a microperveance 2.0 tube. The tuning of the additional cavities is based on the Bunching, Alignment, Collecting (BAC) approach presented in [4].

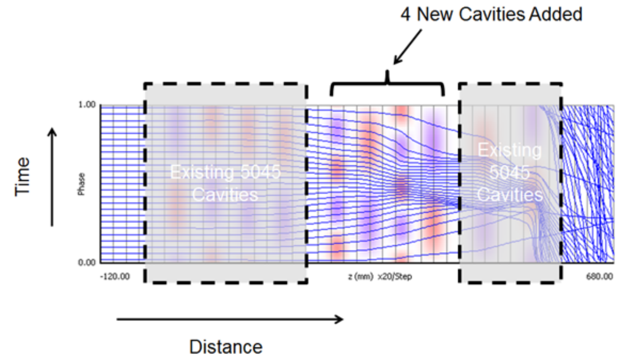

Figure 4. Phase Trajectories for a High Efficiency 5045

Summary

The 5045 klystron is being retrofitted for higher efficiency operation. Optimization of the circuit is presently underway. When a final design is settled upon, a retrofitted 5045 will be constructed and tested. A pulsed depressed collector [2] will be developed in conjunction with the aforementioned changes to the circuit with the goal of achieving an overall 80%+ tube efficiency

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