Numerical Design of High Efficiency Klystrons using Core Oscillation Bunching

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Abstract:
1-D and 2-D numerical simulations of 800 MHz klystrons with efficiencies approaching 90% are presented. While traditional klystrons employ monotonic electron bunching along their lengths, the core oscillation method allows for an improved bunch shape at the output cavity, facilitating maximum energy extraction. The core oscillation bunching scheme proves an attractive method for attaining high efficiency operation in klystrons, which can be used to reduce the power consumption of future particle accelerators.

Introduction:
Future large scale particle accelerator projects, such as the Compact Linear Collider (CLIC) [1] and the Future Circular Collider (FCC) [2] will require a significant amount of RF drive power. For comparison, FCC is projected to have a tunnel length of ~100 km, in comparison to the 27 km tunnel at LHC. As a result, the RF requirements of FCC will be significantly larger. At LHC, the RF drive is produced by 16, 400 MHz, 300 kW continuous wave (CW) klystrons, operating with an efficiency of ~65% [3]. FCC is projected to require 100 MW of CW RF drive power at a frequency of 800 MHz [1], necessitating a significant number of suitable vacuum tubes.

In terms of efficiency, the limiting factor in the design of future particle accelerators lies with the RF power source. Therefore, to mitigate the RF demands, it is attractive to examine methods of improving the efficiency of the RF drive. For a klystron, one of the limiting factors for high efficiency operation is the shape of the electron bunch as it reaches the output cavity. To ensure maximum energy extraction from the bunch to the output RF signal, the phase and spatial profile of the bunch must be such that after the bunch has been decelerated by the output gap, each particle has identical velocity. In addition, the particles should not be reflected toward the cathode.

A method of attaining such a bunch profile is through core oscillations [4,5]. Rather than electrons moving monotonically towards the centre of a bunch along its length, as in a traditional klystron, the core of the bunch is allowed to contract and expand between cavities, while outlying particles are brought into the bunch. This behaviour can be seen in Fig. 1, below. While this method results in klystrons of increased length, their efficiencies are predicted to approach 90% [4,5], as almost all of the particles exist within a bunch when they reach the output cavity.

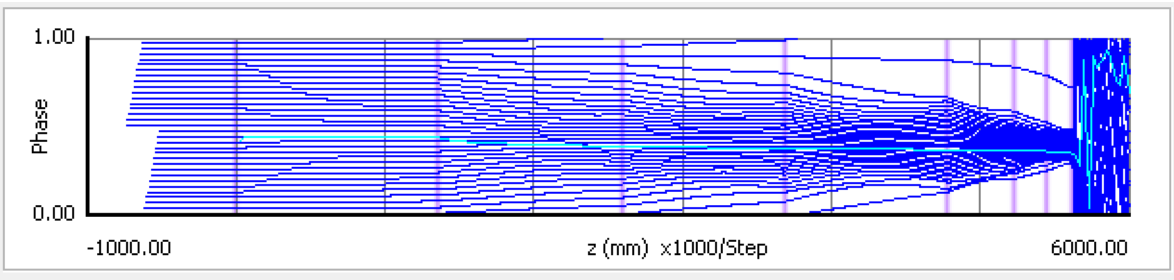

Fig. 1 Illustration of the core oscillation bunching method, from AJDisk.

Numerical simulations:
Numerical simulations of several configurations operating at 800 MHz are currently in progress, using the 1-D klystron disk modeller, AJDisk, and the 2-D PIC code, Magic. Using an electron beam of ~120 kV, 15.08 A, a six cavity geometry (seen in Fig. 2a) has predicted an output power of 1.35 MW (Fig. 2b), with an efficiency of ~76%.

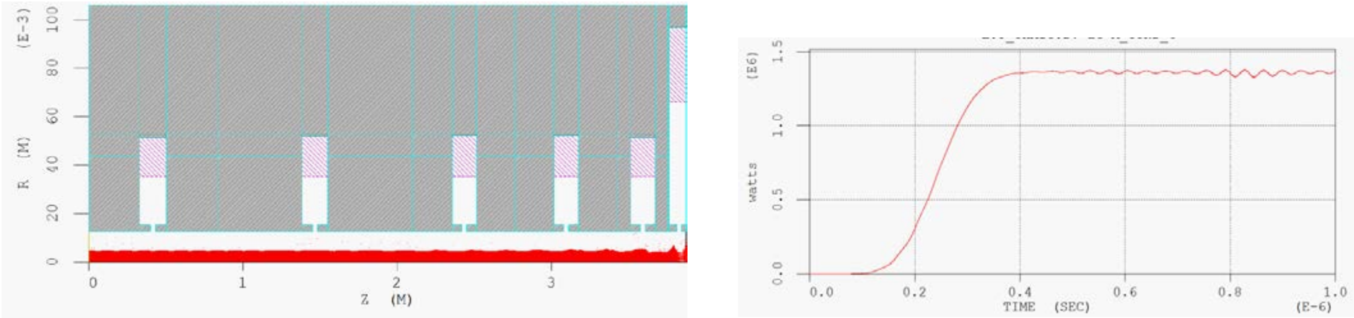

Fig. 2 Example of a) high efficiency klystron structure and b) output power, simulated in Magic 2-D.

While the efficiency of the tube is promising, decelerated electrons losing energy at the output gap result in an electron cloud developing at the end of the beam pipe. This region of space charge results in electrons being reflected toward the cathode region. The current research focus is to attempt to mitigate the reflection of electrons from the output region, while not sacrificing the promising efficiency of the tube.

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