High-Efficiency Klystron with Post Acceleration Progress Report

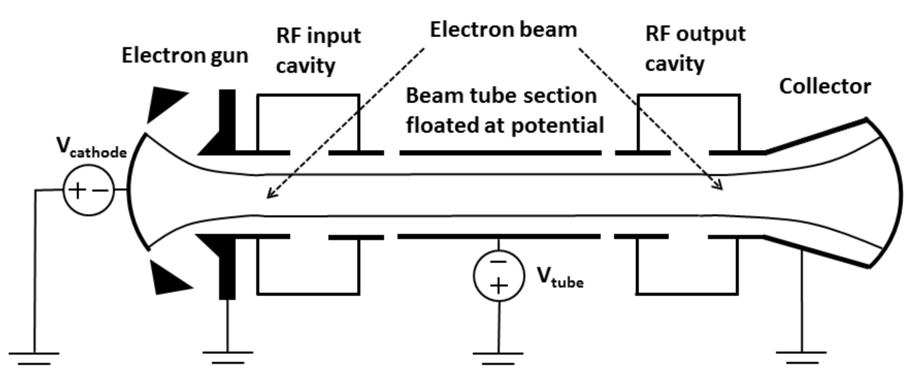
Q3 FY19

Analysis of the nonlinear bunching phenomena started in earnest this last quarter. Both the University of Michigan student, Anna Cooleybeck, and the DOE/SC Visiting Faculty member, Professor Heather Song from U Colorado, Denver, arrived and started to contribute to the project.

The focus of the Q3 activities was to start the systematic parametric study for the nonlinear space-charge bunching to address the critical Task 2 ("Analysis") deliverables (Mid-project evaluation report on post-acceleration klystron architecture (metric: lack of fundamental show-stoppers); Preservation of harmonic current during post-acceleration (metric: > 160% harmonic current after post acceleration); Generation of high harmonic current in voltage depressed section (metric: > 160% harmonic current). The initial goals of this study are to:

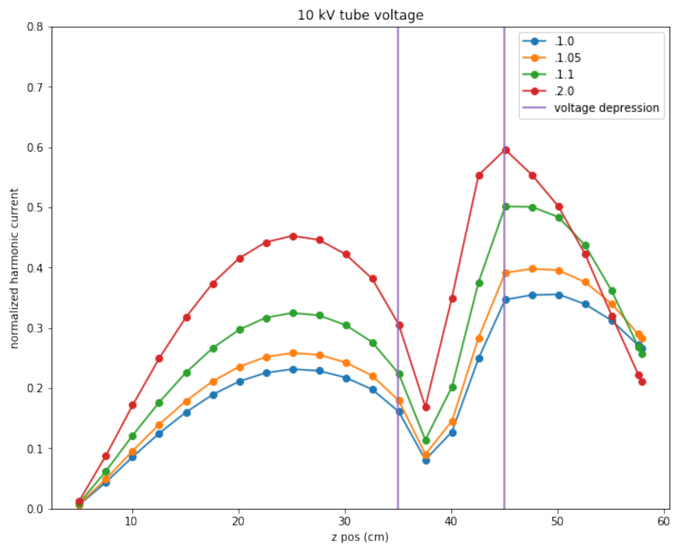
- Identify the threshold conditions for the nonlinear bunching shown in the proposal (using a single modulation cavity)
- Understand characteristics of the nonlinear bunching (using a single modulation cavity)
- Optimize the nonlinear bunching with multiple modulation cavities
- Quantify the beam's energy spread after post acceleration
- We are using the nominal JLEIC klystron parameters for this study (20 kV, 6 A, 956.2 MHz)

For the simulations described below, we are using the exact geometry shown in the proposal, reproduced below.



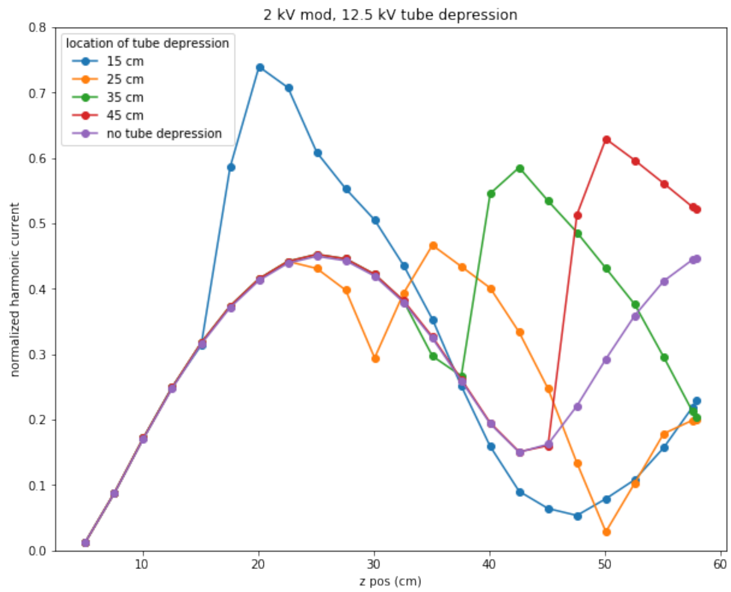
We are using the 2.5D FDTD PIC code TUBE to study the harmonic current as a function of axial position due to modulation in an initial cavity (called the RF input cavity in the figure above). We are also looking at plots of the electron's relativistic axial momentum as a function of axial position to provide insights into the bunching phenomena. We are not including an RF output cavity yet (or, alternatively, we can consider one that is highly detuned and not disturbing the beam).

The plot below shows the harmonic current as a function of axial position downstream from a modulating cavity centered at about 5 cm for different gap voltages (1 kV to 2 kV):



The purple lines show the location of the 10-cm long depressed section, centered at 40 cm, and with a 10 kV depression. These results confirm our understanding of the beam physics in the linear regime (the harmonic current is linear with initial modulation). Also, the effect of the depressed section is to effectively shorten the reduced space-charge wavelength, as expected. It's nice to see a bit of enhanced harmonic current due to the depressed section (i.e.., the second peak of the harmonic current is higher than the first, even for this relatively small amount of voltage depression). This increase in harmonic current from essentially linear space-charge bunching has reminded the project team of the "velocity jump amplifier" (VJA), first proposed by Field, Tien, and Watkins ("Amplification by acceleration and deceleration of a single-velocity stream," *Proc. IRE*, **39** (1951)). We will consider if we can enhance the nonlinear bunching by using the VJA principle.

The plot below shows the harmonic current as a function of axial position, using the same initial cavity modulation (2 kV). The harmonic current is plotted for different locations of the depressed section, now at 12.5 kV for all the cases, except for the purple line which had the depressed section removed. The voltage depressed section is 10 cm long for all the other cases. Again, the purple line shows the expected oscillation of harmonic current from standard space-charge bunching (the fact that it doesn't drop to zero at about 42 cm is because electrons at different radial positions see slightly different space-charge wavelengths). Importantly, we see enhancement of the harmonic current for all cases, even for the orange case where the voltage depressed section is near the first peak of the harmonic current. (Naively, we might have expected the harmonic current to just drop from that location as the primary effect of the voltage depressed section is to shorten the space-charge wavelength.) Since the voltage depression is still pretty low, we expect this harmonic current increase to still be largely from the VJA effect.



We will finish this systematic parameter study by Q4 and hope to include an analysis of the VJA effect on the harmonic current.