HUGHES ELECTRON GUN: TESTING OF THE CHILD-LANGMUIR LAW AND THE STEFAN-BOLTZMANN LAW:

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INTRODUCTION:

The Hughes electron gun is a Pierce-type electron beam source. This allows for focused electron acceleration resulting from the curvature of the cathode. Temperature and emittance have a negligible effect on the beam radius when compared with the space-charge force. The gun accelerates electrons to produce a measurable current beam. The thermal power radiated by the cathode in the gun is dependent on the temperature. The purpose of the experiment is to study the validity of the relationships between accelerating voltage and beam current and between power and temperature.

Explicitly, the Child-Langmuir law eq. 1) predicts the maximum current density (in A/m^2) in a one-dimensional, infinite parallel plane diode to be proportional to the accelerating voltage to the $3/2^{ths}$ power. The Steffan-Boltzmann law eq. 2) states that the power radiated by the hot cathode in watts is proportional to the 4^{th} power of the temperature of the cathode.

$$1) \quad j_{CL} = \frac{4}{9}\varepsilon_0 \left(\frac{2e}{m_e}\right)^{1/2} \frac{V_0^{3/2}}{d^2},$$

$$2) \quad P_{SB} = A\varepsilon\sigma_o\left(T^4 - T_c^4\right)$$

For the Child-Langmuir law, e and m_e are the electron's charge and mass, V_0 is the diode voltage (anode-to-cathode), d is the diode gap (cathode-to-anode distance) and ε_o is the permittivity of free space. For the Steffan-Boltzmann law, A is the area, ε is the emissivity of the cathode and σ_o is the Steffan-Boltzmann constant. There is power loss because the hot cathode is radiating energy to its cooler surroundings at a temperature of T_c measured in Kelvin. Refer to Reiser's book for the derivation for the Child-Langmuir Law on page 39-40.

BACKGROUND:

1. Reiser, M. (1994) "Example of a Pierce-Type Electron Gun with Shielded Cathode". *Theory and Design of Charged Particle Beams*, New York: Wiley pp. 564-566. -
2. Benal, S. (1999). "Study of Transverse Density Waves in an Electron Beam Experiment". (Doctoral Dissertation, University of Maryland, College park, 1999), sec. 3.1-3.3: pp.44-52.

EQUIPMENT:

- Hughes electron gun
- FLUKE 322 Current Meter
- FLUKE 112 Multi-meter
- LeCroy 1GHz Oscilloscope
- Stanford Pulse Generator
- Variable Voltage Transformer (Variac)
- Tektronix High Voltage Probe
- Micro Optical Pyrometer
- Pearson Current Monitor
- High Voltage Power Supply

PROCEDURE:

1. Record basic operating e-gun conditions: current, temperature and pressure in the gun and in the cathode. Use the full-beam aperture (14.4 mm in diameter). The cathode heater current should be close to 9.0 amperes and the temperature at a maximum of 1200 ^{o}C.
2. Power on the HV box and the low voltage power supply (LVPS). Allow 5 minutes for the supply to warm up. The supply should be set to produce long thyratron current pulses.
3. Power on the oscilloscope and display the beam current on channel 4 (green) and the HV on channel 2 (red). The Stanford pulse generator should already be triggering the scope and the high voltage power supply (HVPS).
4. Ensure that the HV control is all the way down and then power on the HVPS.
5. Take measurements of the accelerating high voltage vs. the beam current using the cursors on the oscilloscope. Use a maximum high voltage of 10 kV first, and then reduce the accelerating voltage by increments of 0.5-1.0 kV. Record your data on paper. Never adjust the Variac when taking data for beam current. This will change the cathode current and skew the results.
6. Once finished, turn down the HV control and turn off the HVPS. Ask for assistance to assure that the HV is turned off before removing the plastic shield off the gun.
7. After the shield is removed, set the multi-meter to measure the voltage across the cathode. The red lead of the multi-meter should be connected to the black wire attached to the flange and the black lead should be connected to the white wire under the pipe clamp.
8. Assemble the pyrometer and make proper adjustments to focus on the cathode down the length of the gun.
9. Take measurements of cathode voltage, current, and temperature by varying the current output from the Variac transformer. Start with a maximum current around 9.0 A reducing the current by increments of 0.5-1.0 A. The temperature of the cathode below 3.5 A is too low for the pyrometer to measure.

ANALYSIS / QUESTIONS:

1. Tabulate your results and propagate errors in the measurements.
2. Plot power vs. temperature and electron beam current in vs. accelerating voltage.
3. Fit two curves. One for the Child-Langmuir law and another for Steffan-Boltzmann law using fitting parameters. Extract the value of the diode gap from the diode current vs. voltage and the Child-Langmuir law, and the Steffan-Boltzmann constant from the relationship between cathode temperature and filament power. Excel cannot solve fits with parameters that are more than $10^{\wedge -8}$ in magnitude. Find a way around this to discover the Steffan-Boltzmann constant and the diode gap.
4. How well does the diode current vs. voltage agree with the power of $3/2^{ths}$ given by the Child-Langmuir law? What is the cause of the discrepancy between them? Think about the geometry of the gun, the trajectory of electrons and what happens to the focus of the beam before and after the anode. Refer to the Hughes gun sketch.
5. The actual distance between the cathode and anode is around 1 inch. Compare this to the experimental result. What is the largest source of error in the determination of the diode gap measurement and what is its contribution.
6. What is the largest source of error for the Steffan-Boltzmann constant and determine its contribution. What is the value used for T_c? Ideally, this should be exactly room temperature (300K). Comment on the discrepancy and provide an explanation.

EXPERIMENTAL IMPROVEMENTS:

1. Using the cursors on the oscilloscope is an accurate way to measure amplitudes however, they are sometimes unreliable at low voltages. Comment on the error of using the cursors and how to improve reliability for low voltage measurements.
2. Discuss a possible way to correct for temperature changes in the gun when the cathode current is varied.
3. The Child-Langmuir law describes the maximum beam current produced. What assumptions are made when using Child's Law? Does this affect the measurements that were made in this experiment as well?
4. The cathode is a 3-dimentional object with a heater on the back side (refer to the Hughes gun sketch). What assumptions are made when Steffan-Boltzmann's law is used? How does this affect the behavior of the Hughes gun when producing a beam current?
5. Discuss any other improvements that could be made to this experiment.