U.S. Particle Accelerator School 2008, U. of Maryland, College Park
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UMER ELECTRON GUN: TESTING OF CHILD-LANGMUIR LAW
(Also, Basics of Solenoid Focusing)

INTRODUCTION:

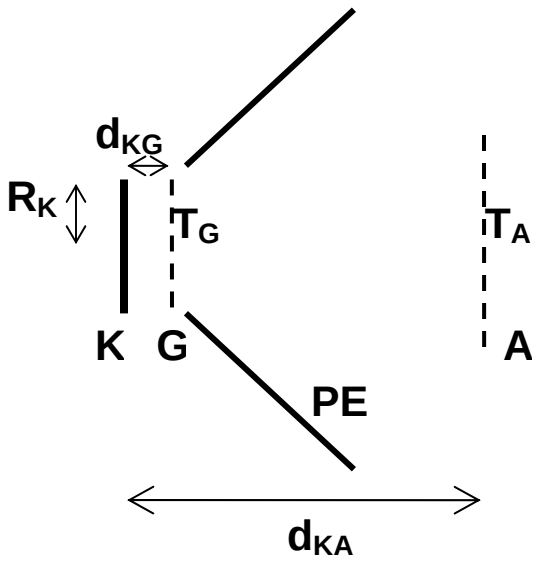
The UMER electron gun is operated most of the time in the space-charge limited regime, where the output beam current I_B is essentially independent of cathode temperature for a given accelerating voltage V_A. Under these conditions, $I_B \sim V_A^{3/2}$. The purpose of the experiment is to study the validity of this relationship in the UMER gun. Although not directly related, a second goal is to learn how focusing/steering depends on the energy of an electron beam.

Explicitly, the Child-Langmuir law states that the maximum current density (in A/m^2) in a one-dimensional diode is given by

$$j_{CL} = \frac{4}{9}\varepsilon_0 \left(\frac{2q}{M}\right)^{1/2} \frac{V_A^{3/2}}{d^2},$$

where q and M are the electron's charge and mass, V_A is the diode voltage (anode-to-cathode), and d is the diode gap (cathode-to-anode distance). As you can read in Prof. Reiser's book, the potential across the diode is $V(x) = V_0(x/d)^{4/3}$; this leads to a zero electric field at the cathode.

While not required for conducting the experiment per se, the schematics below (*not to scale*) and data on the UMER electron gun are useful for quantitative understanding of the gun operation and for answering some of the questions at the end of this guide.



<u>*UMER electron gun numbers*</u>:

Cathode operating temperature:
1100 ^{0}C
Cathode radius:
R_K = 4 mm

Cathode-control grid distance:
d_{KG} = 0.15 mm
Cathode-anode distance:
d_{KA}= 24.1 mm

Control grid transparency:
T_G= 69%
Anode grid transparency:
T_A = 87%

PE: Pierce electrode (67.5^0 to horizontal).

BACKGROUND:

Sections 2.5.1 and 2.5.2 in M. Reiser, *Theory and Design of Charged Particle Beams*; Sec. 6.2 in Miroslav Sedlacek, *Electron Physics of Vacuum and Gaseous Devices* (1996).

EQUIPMENT:

UMER electron gun, matching section (short solenoid, quadrupoles Q1-Q3, and dipole steerers), Bergoz current transformer (BT), Agilent oscilloscope.

PROCEDURE:

1. Record basic operating e-gun conditions (use "Basic Record" sheet).
2. Use full-beam aperture (110 deg. marking).
3. Power the matching section elements in UMER only. Use default matching solution for full beam. Power also the Helmholtz coils over the matching section.
4. Measure mid-pulse beam current at 10 keV with Bergoz transformer (BT). Notice the multiplication factor of the BT: 1.25V/A. Record also solenoid current used.
5. Reduce accelerating voltage to 9 kV and measure beam current again. Turn off all quads and see if it makes any difference. Try reducing the solenoid current slightly (some 0.25A) and see if measured current increases.
6. Measure and record the beam current for accelerating voltages of 8, 7, 6, 5, 4, 3 and 2 kV. You will need to reduce the solenoid current at each step to optimize the current intercepted by the Bergoz coil. Turn off all steering to optimize the measurement at 7 kV and lower voltages.

ANALYSIS / QUESTIONS:

1. Tabulate your results and include measurement errors.
2. Plot electron beam current in mA vs. (accelerating voltage)$^{3/2}$ in (kV)$^{3/2}$.
3. Do a linear fit [include the (0,0) point!] and record the slope and intercept. Do not forget the units.
4. How does the slope from the linear fit compare with the theoretical value from the Child-Langmuir law? The fact that the UMER electron gun has two grids, one in front of the cathode (the control grid) and another one at the anode *will* impact your results (you need the electron gun data given above). Discuss.

5. Physically, why is the electric field zero at the cathode of a space-charge limited diode? One or two sentences will suffice for your answer.
6. Assume that you want 100 mA net output from the UMER electron gun at an accelerating voltage V_A=10kV. Then, 1) what should be the current and current density emitted from the cathode? 2) Ignoring the control grid, i.e. assuming that the gun is just the cathode-anode diode, what is the potential at the location of the grid according to Child-Langmuir if V_A = 10 kV? 3) Now consider the cathode-control grid diode (KG). If Child-Langmuir is valid there, what should be the grid voltage? Based on your answers to 2) and 3), can the UMER electron gun operate in the space charge limited regime in *both* the KG and control grid-to-anode (GA) regions? Discuss briefly.

(Bonus) Solenoid-related questions:

A. Why is less solenoid current required for lower accelerating voltages?
B. Calculate: 1) the magnetic rigidities for 2,3, ...10 keV electrons, 2) the approximate solenoid peak fields for the different currents used in your measurements (see UMER-010500-SB, Matching Section Solenoid), and 3) the corresponding peak focusing functions. What do you conclude about the focal length of the solenoid? (See also M. Reiser's book "Theory and Design of Charged Particle Beams", p. 98-100).