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DESIGN AND OPERATION OF A LAMINAR-FLOW ELECTROSTATIC-QUADRUPOLE-FOCUSED ACCELERATION COLUMN

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The traditional way of accelerating beams in electrostatic devices have been based on Pierce-type focusing. This suffers from the problem that as the voltage is raised, higher and higher electric fields are necessary in order to maintain the current density. Most high-current-density ion sources work best at the highest electric fields obtainable in the extraction region. This typically occurs for voltages of 10-20 keV. If higher voltge is required, the Pierce-type acceleration column will require one to lower the current density. This problem is completely eliminated for the case of a quadrupole-focused acceleration column. In a previous paper[1] it was reported that essentially laminar flow could be obtained in a 25 cell FODO structure. This report deals with the design principles involved in the design of a laminar-flow electrostatic-quadrupole-focused acceleration column. In particular, attention will be paid to making the parameters suitable for incorporation into a DC MEQALAC design.

In a previous report,[2] it was shown that the space charge limited current in a quadrupole channel was proportional to $\mu_o^2 r_b^2 V^{3/2}/L_{cell}^2$. In order to have laminar flow, we must maintain this relation throughout the column. Now the thin lens approximation gives $\mu_o \propto V_Q \ell_Q L_{cell}/(r_Q V)$. Therefore, the laminar flow condition becomes:

$$\frac{r_b^2}{r_Q^4}\,\frac{V_Q^2\,\ell_Q^2}{V^{1/2}} = \text{constant}$$

The basic assumption made below is to keep r_Q and r_b constant throughout the column. This is not absolutely necessary, but the construction of a MEQALAC column is considerably simplified if this is the

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case. For a spherically focusing array, one might actually want all the radii to taper appropriately. The basic relationship is that $V_Q L_Q \propto V^{1/4}$. For the model acceleration column that was tested here, it was convenient to use identical quadrupoles, and hence we had $V_Q \propto V^{1/4}$. In a column with a large ratio of input voltage to output voltage, this rising quadrupole voltage could get awkward. Therefore, in general, one would prefer to keep V_Q constant, and let $L_Q \propto V^{1/4}$. The natural thing, in this case, is to keep the ratio L_Q/L_{cell} constant. Therefore, in general, we would like to have $L_{cell} \propto V^{1/4}$.

The parameters of the model acceleration column were $V_{out} = 4\ V_{in}$, and the voltage increased by approximately 15% per quadrupole. Strictly speaking, a voltage gain of 4 in 10 gaps. The initial quadrupole parameters were taken from our previous work that indicated where we got the brightest beams. This was with $r_Q/L_{cell} \approx 0.106$, and $\mu_o \approx 75°$, or $V_Q \approx 0.1\ V_{in}$. The cell length was put proportional to $V^{1/4}$, as was V_Q, since ℓ_Q remained constant. Note that μ_o is proportional to $V^{-1/2}$.

Now if one continued to increase the voltage in steps of constant ratio, the electric fields in the gap between quads would increase. Before one reaches the sparking limit, one would reduce the acceleration rate to avoid this. Remember, that unlike a Pierce column, there is no requirement on the acceleration rate in a quadrupole focused column.

The ultimate performance of an acceleration column can be compared with the performance of an ideal Pierce column. For a Pierce column one has, from the Child Langmuir law that the curent density J, in amperes/m^2, is given by:

$$J = 5.44 \times 10^{-8} \frac{V^{3/2}}{A^{1/2} d^2}$$

where A is the atomic number of the ion, and d is the length of the acceleration column.