DESIGN DESIDERATA FOR A LAMINAR FLOW QUADRUPOLE-FOCUSED
ACCELERATION COLUMN*

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The "Pierce" design acceleration column has been widely used to accelerate high current beams. It operates well in the space charge limited condition, and will produce beams with a temperature comparable with that of the source. It is restricted in current density, however, by the Child-Langmuir relation. If the ion source itself is not the limiting constraint, then the achievable current density is limited by the electric field at which sparking occurs.

$$J = 5.44 \times 10^{-8} \frac{E^2}{V^{1/2}} \quad (1)$$

where J is current density in amps/m², E is the electric field in the column and V is the terminal potential. One sees clearly that the achievable current density decreases as one goes to higher voltages. This can be easily overcome by using electrostatic quadrupole focusing in the acceleration column.

Now it can be shown¹ that the space charge limited current density in a constant energy quadrupole transport channel is greater than that given by Eq. 1, if one assumes that the electric fields on the quadrupoles can be as high in the ion source extraction electric fields. In practice, this is a conservative assumption. It follows that if the beam can be transported a large distance at the C-L current density limit, it can surely be accelerated as it goes from quadrupole to quadrupole. Hence, the necessity of having a high gradient acceleration column goes away.

The design of a laminar flow quadrupole-focused acceleration column can be broken down into two parts. One is to match the ion source into the beginning of the acceleration column. We did this by building a transport system consisting of about twenty electrostatic quadrupoles. The beam can then be analyzed at the exit. In this way one can empirically determine when a space charge limited laminar flow condition has been achieved.

With this having been done, we know the proper geometry and voltage for the first quadrupole of the acceleration column, when the beam has only the energy of the extraction voltage. Now it only remains to know how to change the quadrupole parameters as

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one goes up in voltage. This is given by the laminar flow condition:²

$$\left[\frac{r_b}{r_q}\right]^2 \frac{E_q^2 \ell_q^2}{V^{1/2}} = \text{constant} \quad (2)$$

Here r_b is the beam radius, r_q the quadrupole half-aperture, E_q is the electric field in the quad, ℓ_q the quadrupole length and V is the energy of the beam in the quadrupole of interest. The only other constraint is to make sure the optical changes from quadrupole to quadrupole are gradual. This translates into a design which does not change the beam energy by a large amount in a single gap. For the column that we tested here, the change was limited to 15% per quad., i.e., a factor of four in voltage in the space of 10 quads.

The usual situation would be to keep the beam radius and quadrupole radius constant. Also, if the electric field was high at the beginning, one might chose to keep it constant also. In this case the only variable is the quadrupole length. One has then that $\ell_q \propto V^{1/4}$. In the acceleration column that we tested here, we used ten identical quadrupoles (because we had them) and let the quadrupole voltages increase as $V^{1/4}$. This was no problem because the electric fields were low. Notice that the spacing between the quadrupoles does not explicitly enter the relationship for laminar flow. However, the phase advance/cell increases as the quad separation increases. Above 90° the thin lens approximation breaks down. This is not a practical limitation, since stable laminar flow is usually seen around 70-80° phase advance. In the column we tested, we let the cell spacing vary as $V^{1/4}$ also. This gives a phase advance/cell which goes as $V^{-1/2}$.

References

1. Formulary for MEQALAC Design, BNL 51119 (1979).
2. Space Charge Limits for Linear Accelerators, BNL 51022 (1979) and Design and Operation of a Laminar Flow Electrostatic Quadrupole Focused Acceleration Column, BNL 51692 (1983).

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