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FORMULARY FOR MEQALAC DESIGN

A. W. Maschke

MASTER

November 27, 1979

ACCELERATOR DEPARTMENT
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(Particle Accelerators and
High Voltage Machines-TID 4500)

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ABSTRACT

From the space-charge limits for quadrupole transport systems discussed in an earlier report, some simple relations are obtained that will assist in the design of practical systems.

The space-charge limits for quadrupole transport systems have been discussed in an earlier report.¹ The three basic relations which follow from the previous analyses are

$$i_{\max_T} = 1.56 \times 10^7 \left\{ k_{\mu_0}^2 k_3^2 n^{4/3} \right\} \frac{A}{Z} (\beta\gamma)^3, \quad (1)$$

$$= 10.2 \left\{ \frac{k}{(1-k)^{1/3}} (\mu_0 k_4)^{2/3} \right\} \left(\frac{A}{Z} \right)^{1/3} (\epsilon_{NT} E_{Q_m})^{2/3} \beta\gamma^{5/3},$$

$$\epsilon_{NT} = \left\{ n^2 k_3^2 \mu_0 (1-k)^{1/2} \right\} \beta\gamma L_{\text{cell}}, \quad (2)$$

$$E_{Q_m} = 6.26 \left\{ \mu_0 \frac{k_3}{k_4} \right\} \frac{A}{Z} c \frac{\beta^2 \gamma}{L_{\text{cell}}}. \quad (3)$$

Now there are limits on the bracketed variables. In what follows, these values have been taken:

$$k = 0.5$$

$$k_3 = 0.125$$

$$k_4 = 0.4$$

$$\mu_0 = 1.5$$

$$n = 0.707$$

In addition, the parameter V is introduced by the following relation:

$$zeV = \frac{1}{2} m_p A \beta^2 c^2.$$

The quadrupole voltage is given by $V_Q = E_{Q_m} (r_Q/2)$. The basic equations for a current limited quadrupole transport system are given below:

$$i_{\max} = 1.7 \times 10^{-8} \frac{V^{3/2} Z^{1/2}}{A^{1/2}}, \quad (4)$$

$$\epsilon_{NT} = 1 \times 10^{-6} \frac{V^{3/2} Z^{1/2}}{E_{Q_m} A^{1/2}}, \quad (5)$$

$$r_Q = 0.23 \text{ V}/E_{Q_m}, \quad (6)$$

$$V_Q = 0.115 \text{ V} \quad (7)$$

From these relationships we can obtain an equation for the limiting current density, J_Q , and compare this with the Child-Langmuir limit.

$$J_Q \equiv \frac{i_{\max}^2}{\pi r_Q^2} = 10^{-7} \frac{E_{Q_m}^2 Z^{1/2}}{A^{1/2} V^{1/2}}, \quad (8)$$

$$J_{CL} = 5.44 \times 10^{-8} \frac{E_s^2 Z^{1/2}}{A^{1/2} V^{1/2}}, \quad (9)$$

where E_s is the electric field in the extraction gap.

Now since E_{Q_m} is bounded, Eq. (8) infers that the highest current density is obtained in the lowest voltages. Equation (6) indicates that lower voltages and higher electric fields lead to smaller radii. Note that as long as $E_{Q_m} \leq 0.7 E_s$ the Child-Langmuir relation is not a limitation.

Equation (5) puts a limit on the source emittance, which must be less than ϵ_{NT} . The ion source output can be characterized by an effective temperature T_{ev} , which has units of electron-volts. The following relation must hold:

$$T_{ev} \leq .018 \text{ V} \quad (10)$$

The current density requirement can be related to the plasma density in the ion source. The plasma density n must satisfy the relation:

$$zen v^{th} \geq J_Q;$$

then the following relation obtains:

$$n \geq \frac{6.4 \times 10^7 E_{Q_m}^2}{Z^{1/2} V^{1/2} T_{ev}^{1/2}} \quad (11)$$

Assuming that inequality (10) is satisfied, the relation becomes

$$n \geq 4.8 \times 10^8 \frac{E_{Q_m}^2}{Z^{1/2} V} (\text{meters})^{-3} \quad (12)$$

Therefore a lower bound is put on V by the attainable plasma density in the ion source. Since both the effective temperature T_{ev} and the plasma density n depend on details of source design, input power, etc., it is hard to make any further generalization.

It is generally true that a linear accelerator should operate at as high a frequency as possible. Transit time considerations, which are related to the aperture size, put a limit on frequency. Typically, one requires $\beta c/f \geq 8 r_Q$. Therefore,

$$f_{\max} = 7.5 \times 10^3 \frac{E_{Qm} z^{1/2}}{V^{1/2} A^{1/2}} \quad (13)$$

Note that once again it is desirable to move in the direction of low voltage.

The total current that can be transported in a MEQALAC is the product of the current density and the drift-tube area. The drift-tube radius has the following relation to the frequency:

$$r_{DT} \leq \frac{1}{16} \frac{c}{f}$$

Making use of the relationship between peak and average current in a linac, $\bar{i} = 0.133 i_{\max}$, and using Eqs. (8) and (13) with an area filling factor of 1/3, the following inequality results:

$$\bar{i} \leq 0.087 \frac{V^{1/2} A^{1/2}}{z^{1/2}} \quad (14)$$

If a frequency lower than that given by (13) is taken, then a larger current could be accelerated.

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REFERENCE

1. A.W. Maschke, Space-Charge Limits for Linear Accelerators, BNL 51022, May 1, 1979.

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