THE DESIGN OF GRIDDED PIERCE GUNS FOR ACCELERATORS

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ABSTRACT

It is vital to employ ultra-laminar beams in electron linacs to maximize charge transport to the target. This paper presents numerical and experimental design techniques which have led to significant improvements in gridded Pierce guns used in microwave tubes and electron linacs. The paper concludes with two gun/injector concepts which have demonstrated enhanced performance over standard triode Pierce guns.

COMPUTER AIDED GUN DESIGN

Presented in Fig. 1 is a computer simulation of an intercepting gridded Pierce gun. These guns typically use hex mesh grids as shown in Fig. 2, which can be modelled in axisymmetric gun codes as a set of concentric rings. Realistic results are obtained when the cutoff voltage in the ring model approximates that of the hex mesh grid [2] or set up according to Fig. 3.

There are two key points in regard to the model of Fig. 1. First, in designing a gridded gun, it is essential to include the effect of the grid, thus the model must include a representation of the actual grid to be used. Second, it is advantageous to use a deformable mesh code [1] in solving such problems because the blend of accuracy, quick processing speed, and convenient interpretation of results makes this approach preferable from an engineering point of view.

In using the deformable mesh code to solve a gridded gun problem, first a logical diagram is set up as shown in Fig. 4. The number of rays simulating the beam was chosen to provide a grid interception of 11%, which corresponds to the geometrical screening of the hex mesh grid. The computer then automatically sets up the relaxation mesh on which the problem is solved as shown in Fig. 5.

EVALUATION OF GUN PERFORMANCE

In any given gridded gun design, there is a unique grid voltage setting (hence perveance) which provides the most laminar beam. This best operating point typically occurs near the vertex of a plot of beam filling factor (r_c/a) times beam filling factor (r_c/a). Such curves can be obtained from either gridded gun simulations (such as that of Fig. 1) or by experimental methods [2].

Figure 6 shows the effect of varying the cathode-to-anode spacing, d, in an accelerator gridded gun. It can be seen that as d is increased, the optimum operating perveance shifts to a lower value and the beam radius shrinks. It is useful to compare the top point of curve P with the vertex point of O. The grid is overvoltaged in the case of P for a perveance similar to that of O which tends to pull electrons towards the grid wires and upset the radial flow pattern. In the case of the rightmost point of O versus the vertex point of P, the grid is undervoltaged in the case of O which scatters electrons away from the grid which increases σ and limits beam compression.

There is an important implication from the above in regard to grid design. That is if the grid does not coincide precisely with an equipotential contour, part will be overvoltaged and part undervoltaged at the best perveance leading to a worse σ than might be achieved otherwise. In the gun of Fig. 1, when the grid and cathode spherical radii are equal, the most laminar beam is produced.

When thermal velocity effects are included, the net beam σ increases and the curves tend to shift to the right. The conclusions of the preceding paragraphs, however, are in no way invalidated, thus it is justifiable to utilize a zero temperature computer model for design purposes. Extra beamlets can be launched which simulate a thermal beam for a more accurate determination of σ after the gun design has been fully worked out.

SIMPLIFIED DESIGN TECHNIQUES

It is interesting to compare the results of Fig. 1 with author’s formula for gun design [1]. Substituting a value of 2.03 for beam microperveance and 3.24 for beam linear convergence into

$$\theta_0 = 12.9 \sqrt{|P|} |r_c/r_v|$$

yields a gun half-angle of 33.1° which differs from the actual 8° by less than 1°. In a similar fashion, θ obtained from Vaughan’s method [3] agrees closely with the actual θ.

TRIODE GUN WITH POSTACCELERATOR

Figure 7 presents a concept which has been used in free electron laser experiments [4,5]. The main advantage to this arrangement is the fact that a low-β beam can be produced over an enormous perveance range. Scaling the grid and anode voltages by the same ratio enables beam current to be varied without degrading laminarity. An additional feature of this arrangement is related to gun arc protection. Biasing the anode through a high impedance supply frequently helps to prevent high voltage arc damage.

ULTRA-LAMINAR TETRODE GUN

Another gun concept which is very useful for high duty cycle accelerators is shown in Fig. 8. In this gun, a low-voltage grid adjacent to the cathode shields the control grid which thus prevents grid overheating. Duty cycles about an order of magnitude higher than for intercepting gridded guns are possible with this arrangement. The author has shown that β for such guns can equal or better than in equivalent triode guns [6].

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REFERENCES


Fig. 1. Computer simulation of triode Pierce gun using deformable mesh code [1].

Fig. 2. Boresight view of typical cell of hex mesh grid used in accelerator triode guns.

Fig. 3. Concentric ring approximation of hex mesh grid. In ring model F, T, w, and Rg equivalent to hex mesh grid.
Fig. 4. Logical diagram for gun problem of Fig. 1.

Fig. 5. Zoom view of deformed triangular mesh on which Poisson's equation is solved.

Fig. 6. Hairpin curves [2] for Lillius M-572 medical accelerator gun summarizing the effect of cathode-to-anode spacing, d, on performance. (θ = 34°, r_c = .3175 cm, V_a = 8 kV and a = .1 cm)

Fig. 7. High perveance gun of Fig. 1 with postaccelerator section. This concept has been used in an injector to a free electron laser linac.

Fig. 8. Zoom view of .25 μm ultra-laminar tetrode gun [6]. In the figure: V_g1 = 12.6 V, V_g2 = 143.2 V and V_a = 10 kV.