ELECTRON GUN FOR A HIGH-POWER X-BAND MAGNICON AMPLIFIER

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Abstract

This paper presents a high-power, high brightness gun design for an 11.4 GHz magnicon amplifier. Results of gun geometry optimization, and gun matching to the magnetic system, are described. A method to eliminate beam halo, decrease beam emittance, and reduce the effect of gun tolerances, is proposed.

I. INTRODUCTION.

The magnicon is a new RF source with circular beam deflection invented in the 1980's at Budker INP [1,2]. An 11.4 GHz magnicon [3] is being developed jointly by Omega-P, NRL, and Litton as a potential very high efficiency RF source for future supercolliders. The magnicon under development is a second-harmonic amplifier designed to provide 60 MW 1.5 µsec pulses at a repetition rate of 10 pps. This paper describes a 500 kV, 210 amp (0.59 microperv) gun and beam focusing system design for this RF source.

According to [1] and investigations reported in [4], the focused beam diameter in a magnicon magnetic system must be small in order to achieve high efficiency. Small beam diameter requires that the gun be carefully matched to the main magnetic field. In the magnicon under development, the main field of 6.5 kG is capable of focusing an idealized beam of about 1.3 mm (the Brillouin diameter). We have achieved a diameter close to the Brillouin limit (1.5 mm) which is quite acceptable for achievement of the magnicon performance goals stated above.

A 7.5 cm diameter, 30 degree half-angle cathode is used in this gun. The peak current density in this case is less than 5 A/cm^2 which is consistent with very long dispenser cathode life. The beam area compression ratio is 2500:1.

A unique feature of the gun is use of an electrically isolated focus electrode biased negative with respect to cathode [5]. This serves to reduce or eliminate beam halo, decrease beam emittance, helps to overcome the effect of gun tolerances, and, thus, helps in the achievement of high beam compression and intensity.

Our level of confidence is high in achieving all of the goals reported herein in view of the fact that a 100 MW gun with high beam compression has been built for the Novosibirsk 7 GHz magnicon and is working successfully. This gun has a measured beam compression ratio of 2300:1 at a microperveance level of 0.83 [6]. The present gun design is based partly on this experience.

II. GENERAL

The gun layout is presented in Fig. 1. In the design, the shape of the electrodes was optimized to achieve the required perveance, beam compression, and acceptable electrostatic field gradient levels.

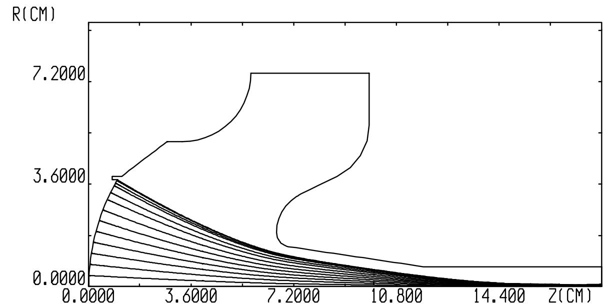

Fig. 1. The gun layout and electron trajectories

1. The initial design was developed using DEMEOS [5] (a finite element method (FEM) code utilizing six linear triangle elements [7]). The final design optimization was carried out using SUPERSAM (a FEM code which uses second-order quadrangle elements [8]). Both codes use a relativistic beam model and agreement of the results is excellent. To simulate gun matching to the magnicon magnetic system taking into account thermal emittance, PIC code BEAM [6] was used. Beam dynamics were simulated in a realistic magnetic field obtained from the SAM code [9].

2. The following physical factors may increase the equilibrium beam diameter in the magnetic system:

-residual cathode magnetic field;

-geometrical aberration;

-thermal emittance.

The equilibrium beam radius r_0 in the uniform magnetic field may be estimated by the formula [6], which may be obtained from Vladimirsky-Kapchinsky equation:

$$r_0 = (r_b^2 /2 + (r_b^4 /4 + r_h^4 + r_m^4)^{1/2})^{1/2} \qquad (1)$$

where r_b is Brillouin radius, r_h is "thermal" equilibrium radius (i.e., the beam radius of a beam emitted from a

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perfectly shielded cathode without taking into account space charge), and r_m is "magnetic" equilibrium radius (i.e.,the minimal equilibrium radius of a beam with zero emittance without taking into account the space charge). According (1), to get a beam diameter of 15% greater than Brillouin, it is necessary to have a residual cathode magnetic field not greater than 1.2 G, and a total effective transverse emittance not greater than 2.5π mrad-cm. Effective emittance is determined by thermal emittance and geometrical aberrations. The gun geometry is chosen to compensate the anode aberration by the "near-cathode" one [6].

3. The aberration caused by the gap between the focus electrode and the cathode is compensated in general by applying a negative potential of few hundred volts (with respect to cathode) to the focusing electrode. This potential not only improves the beam optics near the cathode edge, it also eliminates emission from the side of the cathode which is often the major ultimate origin of beam halo. The beam thermal emittance is about 1.6π mrad-cm which does not significantly influence the beam diameter in the magnetic system.

4. The following method is used to match the gun to the magnicon magnetic system. First, the input pole piece of the magnetic system is placed in the plane of the beam minimum without any magnetic field. Next, the gun optics are chosen such a way that the minimal value of beam radius r_{min} is located on the magnetic force line, which coincides in the magnetic system with the equilibrium beam envelope having radius of r_0, i.e., $r_{min}=r_0\sqrt{2}$. Finally, the radius of the hole in the input pole piece is chosen to match the magnetic force lines and beam trajectories before the magnetic system entrance [6]. Calculations show that it is possible to achieve good matching this way.

5. The electric field gradient off the main focus electrode must be low enough to avoid high voltage breakdown in the gun. Empirical relationships and data on high voltage breakdown are given in [7,10]. Based upon these works, the tolerable gradient level for reliable operation even at 2 μsec is approximately 200 kV/cm. In the magnicon gun the shape of the focus electrode is optimized such that the peak negative surface gradient is 186 kV/cm, which should be quite safe.

III. THE RESULTS OF SIMULATIONS

1. The optimized gun geometry with electron trajectories is presented in Fig. 1. Calculated beam effective emittance (caused by geometrical aberrations only) is less than 0.5π mrad-cm. The beam minimum radius without magnetic field is 0.92mm. Inhomogeneity of emission is not greater than 1.3:1 excluding the cathode edge. 2. Fig.2 shows equipotentials and trajectories for the case of optimal negative voltage on the focus electrode (-400V with respect to the cathode). The equipotential lines are almost parallel to the cathode surface in the gap between the cathode and focus electrode. We made more detailed investigations of the electron flow near the cathode edge. Its real shape was simulated by a round edge of 50μm radius.

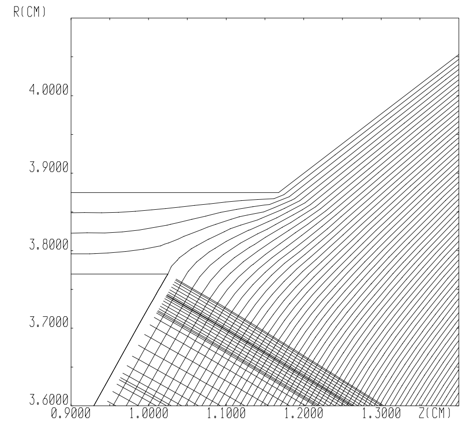

Fig. 2. Equipotentials and trajectories near a gap between the cathode and the focus electrode.

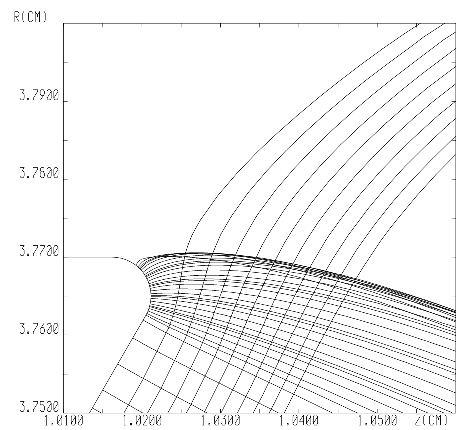

Fig. 3. Some equipotentials and trajectories near the cathode edge.

The size of area with distorted optics is about the round radius, i.e., 50μm (see Fig.3). The total current emitted from the edge is about 1 A. It gives a very small contribution to the beam emittance compared to another sources.

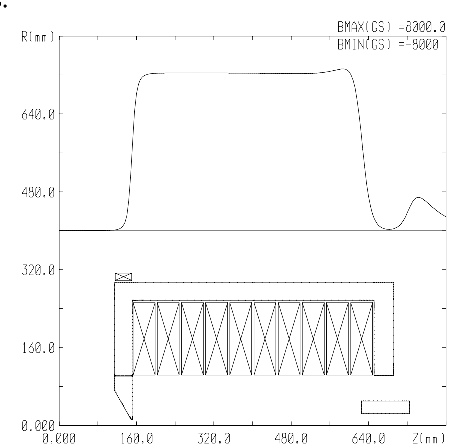

Fig. 4. Magnetic system layout.

3. The magnetic focusing system layout and axial magnetic field distribution are shown in Fig.4, and Fig.5 presents optimized beam envelopes in this magnetic system containing different fractions of the total current. The thermal emittance was not taken into account. The amplitude of beam scalloping is not greater than 5%. Thermal spread of velocities gives the halo which contains 3% of the beam current. 97% of the beam current lies within a radius of 0.75 mm. This gives a beam current density of 12 kA/cm^2, a pulse power density of 6 GW/cm^2 and an energy density of 9 kJ/cm^2 for a pulse duration of 1.5 μsec.

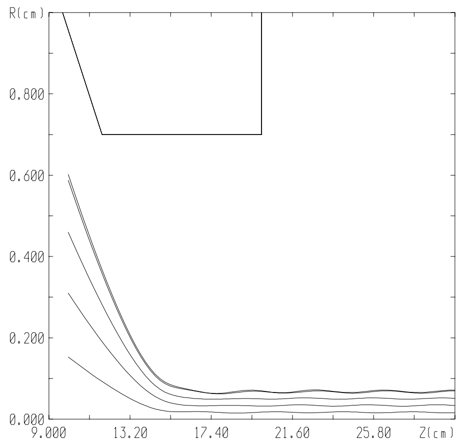

Fig. 5. The beam envelopes containing 6%, 25%, 56%, 95%, 100% of total current, respectively.

4. As was mentioned above, the electrically isolated focus electrode provides the ability to compensate for positional differences between the cathode and focus electrode via adjustment of the focus electrode voltage. This reduces the tolerance which must be held between the cathode and focus electrode. Figure 6 shows plots of maximal beam radius in the magnetic system versus cathode position for zero voltage, and optimal negative voltage applied to the focus electrode. These data indicate that spacing differences of ±0.2 mm are quite acceptable for the optimal negative voltage case.

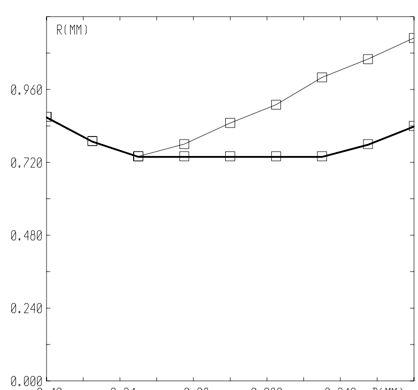

Fig. 6 The beam radius in the magnetic system versus the cathode position for optimal negative voltage (lower curve) and with zero voltage (upper curve).

IV. SUMMARY

The gun design parameters are:

Beam current, A	210
Beam voltage, kV	500
Microperveance	0.59
Pulse duration, μsec	1.5
Repetition rate, pps	10
Cathode radius, mm	37.5
Beam radius in magnetic system, mm	0.75
Beam compression	2500:1
Maximal electric field on the focus electrode, kV/cm	186
Maximal electric field on the anode, kV/cm	265
Beam transverse emittance, mrad-cm	1.6π
Beam current density, kA/cm^2	12.0
Beam power density, GW/cm^2	6.0
Beam energy density, kJ/cm^2	9.0

V. ACKNOWLEDGMENTS

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