100 MW ELECTRON GUN FOR A 34.3 GHZ MAGNICON *

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Abstract

A 100 MW advanced Pierce gun is described that was built for a 34.3 GHz magnicon amplifier. The gun has a computed beam diameter of ~0.9 mm when matched into a 13 kG magnetic field. The diameter of the cathode is 50 mm. Hence, the beam area compression ratio is ~3000:1.

1 INTRODUCTION

The magnicon, a RF source based on circular deflection of an electron beam, is an attractive alternative to the klystron for accelerator applications [1]. Currently, a 34.3 GHz magnicon [2] is under construction by Omega-P, Inc. This magnicon is expected to have a peak output power of 45 MW in a 1.0 μsec pulse with repetition rate of up to 10 Hz. This paper describes a 500 kV, 220 A (perveance ~ 0.62×10^{-6} A-V$^{-3/2}$) gun for this RF source. The gun provides a low emittance electron beam with diameter of 0.9 mm in the magnicon superconducting magnetic system with a field of 13 kG. The Brillouin limit diameter is about 0.7 mm.

2 THE GUN DESIGN

The gun described here is a Pierce diode with extremely high beam area compression. The main gun parameters are listed in Table I. In order to obtain reasonable cathode lifetime (20,000-30,000 hrs), the dispenser cathode diameter is chosen to be 50 mm, limiting loading to 12 A/cm^2 [3]. To achieve required beam diameter in the magnicon magnetic system (see Fig. 1 and Ref. 2), two stage compression is used [4], as proven for the 7 GHz magnicon [5], and for the 11.4 GHz magnicon [6]. Compression in this gun is only partially electrostatic (500:1), since more than this would lead to a higher electric field at the focus electrode; and would require a magnetic field of about 13 kG at the edge of the pole piece, leading to saturation in the iron [4]. Thus, magnetic compression of about 2:1 occurs as the beam passes through the hole in the pole piece into a ~5 kG field, and a further factor of 3:1 occurs adiabatically as the magnetic field gradually rises up to 13 kG.

The gun schematic and simulated trajectories are shown in Fig. 2. The shape of electrodes was optimized to achieve the required perveance, acceptable electrostatic field gradient level and minimum geometrical aberrations.

Table I. Design parameters of the gun for the Omega-P 34.3 GHz magnicon.

beam power, MW	109
beam voltage, kV	500
beam current, A	218
perveance, A-V$^{-3/2}$	0.62×10^{-6}
pulse duration, μsec	1
cathode diameter, mm	50
beam diameter in magnetic system, mm	0.9
beam area compression ratio	3000:1
electrostatic compression	500:1
magnetic compression	6:1
maximum electric field on the focusing electrode, kV/cm	238
maximum cathode loading, A/cm^2	12
transverse beam emittance, mrad-cm	1.0π
aberration contribution to the emittance, mrad-cm	0.2π
beam energy density in magnetic system, kJ/ cm^2	17

The product of maximum surface electric field E_{max} and gap voltage V which characterizes the gun electric strength [7] is $1.2\cdot10^4$ (kV)^2/mm. This is below the value ~$1.5\cdot10^4$ (kV)^2/mm for high-voltage guns for X-band klystrons at SLAC operating with longer pulses [7,8].

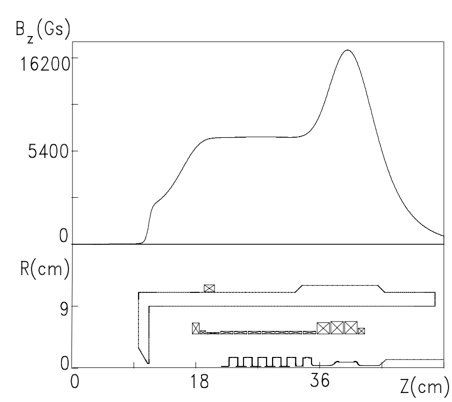

Figure 1. Magnetic system layout and magnetic field profile.

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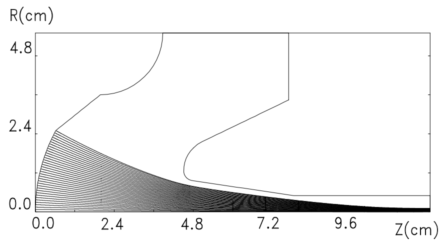

Figure 2. Gun electrode outlines and sample computed electron trajectories, as computed using SuperSAM [9].

Stray magnetic field on the cathode is cancelled using the compensation coil shown in Fig.1 on the outer side of magnetic yoke.

The fundamental limitation on the beam diameter in a magnetic system for a gun with compensated geometrical aberration is due to the beam thermal emittance [4].

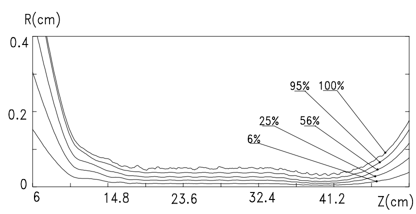

Figure 3. Computed radial limits for 6%, 25%, 56%, 95%, and 100% of the beam current.

In Fig.3 are shown beam envelopes contours calculated taking into account thermal spread of the transverse velocities of the beam electrons. In the region where magnetic field is 13 kG, the beam radius is still close to Brillouin, with 100% of the current within a diameter of 0.9-mm, and 95% within 0.8-mm.

In addition to thermal spread of transverse velocities, cathode surface roughness may contribute to the effective beam temperature if the roughness scale *d* is greater than the distance between the cathode and the potential minimum (virtual cathode). Simulations show that the roughness contribution to the effective beam temperature ΔT may be estimated by the following formula: $\Delta T[°\mathrm{C}] \approx kj^{2/3}[\mathrm{A/cm}^2]d^{4/3}[\mu]$, where *j* is the cathode current density, and *k* is a factor of order unity. For dispenser cathodes, surface roughness scale *d* is a few microns, so for a current density of 12 A/cm^2 the effective temperature increase caused by the cathode surface roughness is less than 50°C.

Another cause for increase of beam emittance and halo formation is the electron emission from the cathode edge and from the cylindrical side of the cathode. To suppress this emission in the gun for the 11.4 GHz magnicon [6] an electrically isolated focus electrode biased negative with respect to the cathode was used. However, it is technically complex to realize this arrangement. In the gun described here another method is applied, in which the cathode edge is surrounded by a molybdenum ring, cut at the Pierce angle with respect to cathode surface. The thermal gap is 3 mm from the cathode edge, and its width is not greater than 0.2 mm when heated, and thus does not affect the beam. Numerical simulations of tolerances show that the gun and magnetic system optics are robust, with misalignments of gun elements of ±0.1-0.2 mm being acceptable.

The de-mountable gun engineering design is shown in Fig. 4. The sectioned insulator is 200 mm in length and 250 mm in diameter, and consists of ten sections. The shapes of intermediate electrodes and the cathode stem are optimized to provide uniformity along the insulator in the potential distribution to within 10% (see Fig.5). A dispenser cathode with osmium coating manufactured by TORY (Moscow) is used. The cathode heater is potted. Temperature variation over the cathode surface <5 °C, and required heater power <300 W. The anode nose is made of molybdenum. The gun is installed with two 8 l/sec pumps. All the critical elements are fabricated and assembled with accuracy < 0.1 mm.

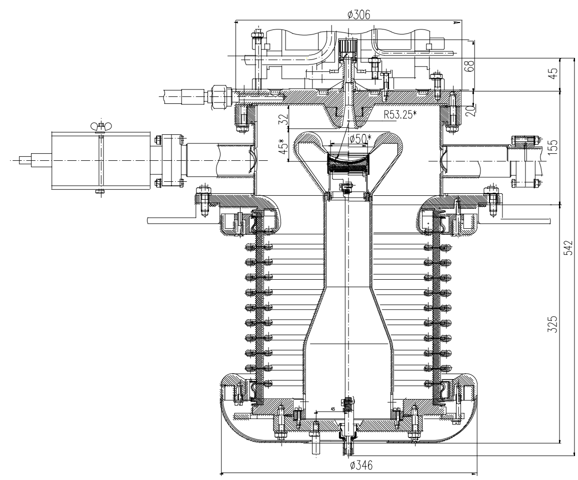

Figure 4. The gun engineering design.

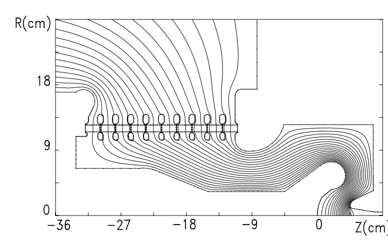

Figure 5 Equipotential lines calculated by SAM code [10].

3 EXPERIMENT

At present the gun is assembled with the magnicon collector [2] and has been tested up to the design power of 100 MW in μsec pulses at the Yale Beam Physics Lab.

The gun is driven by a 500 kV pulse transformer and PFN modulator. Initial conditioning up to ~515 kV was carried out without beam current. To do this, a matched load was connected to the primary of the pulse transformer. The pulse is shown in Fig. 6.

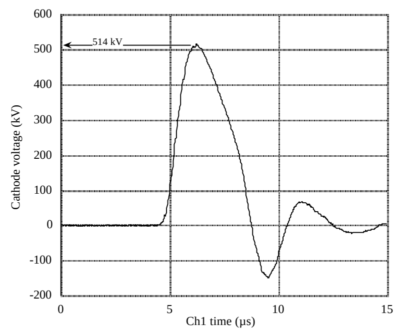

Figure 6. Conditioning pulse without beam current.

After cold conditioning, the gun was conditioned and tested hot up to ~480 kV and ~200 A. To reach 500 kV small modifications in the modulator are required. The gun voltage and current pulses are shown in Fig. 7.

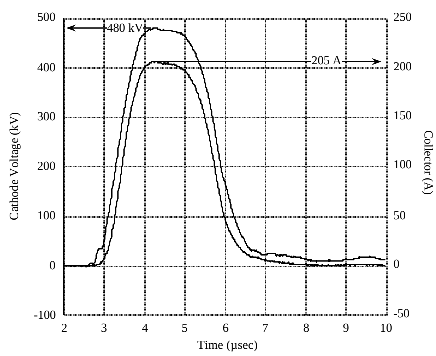

Figure 7. Measured gun voltage and current pulses.

The measured beam current is in excellent agreement with the design value, with differences within the measurement error, or better than ±2%. Gun current plotted *vs* voltage is shown in Fig. 8. Measurements below 100 kV were performed by vendor (Budker INP, Novosibirsk). Even for very small voltage (2 kV) the

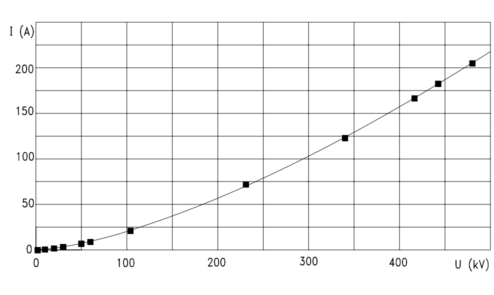

Figure 8. Beam current versus voltage.

measured beam current is only 14% higher than the calculated value. This provides strong evidence that the cathode assembly is positioned with high accuracy with respect to the focus electrode, and that there is negligible electron emission from the cathode edges.

4 CONCLUSIONS

The gun has been tested and is ready for installation on the 34.3 GHz magnicon. Beam current measurements show that the perveance is equal to the design value, within ±2% measurement accuracy. This indicates that the critical gun dimensions are within required tolerances, and consequently that the electron optics should be close to the design.

The gun described here is the third 100 MW beam power level gun with high beam area compression (>1000:1) built for high-power magnicons. Experience with guns for the 7 GHz magnicon [5] (having a measured beam area compression of 2300:1), and for the 11.4 GHz magnicon [11] (having a compression of about 1500:1), shows that even if the gun is fabricated with unintended inaccuracy [11], and even if it's perveance differs from the design value as much as 10-15%, that the measured beam diameter still exceeds the Brillouin limit by no more than 40%. For the gun described here these considerations imply that the beam diameter will not exceed 1.0 mm in the magnicon's 13 kG magnetic system, with an area compression ratio of greater than 2500:1.

5 REFERENCES

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