A Cusp Electron Gun for Millimeter Wave Gyro-Devices

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Abstract:
A thermionic cusp electron gun has been designed, numerically optimized and experimentally measured and is presented. A 40 kV, 1.5 A annular axis-encircling electron beam has been simulated to generate a beam with low velocity and alpha spreads. The electron gun performance has been verified through experiments and the results are given.

Introduction:
High-power high-frequency coherent radiation sources in the millimeter to sub-millimeter wavelengths have attracted significant research interest recently. Gyro-devices are promising candidates to fulfil this demand due to their inherent fast-wave interaction. Many gyro-devices operate at harmonics in order to reduce the required magnetic field strength by a factor of s, the harmonic number. In order to drive the harmonic interaction a mode-selective electron beam is required. An axis-encircling electron beam is ideal for harmonic interaction as the harmonic of the beam's cyclotron mode only interacts with the azimuthal index of the waveguide mode. The cusp electron gun uses a non-adiabatic magnetic field reversal to impart rotational velocity, through the conservation of canonical momentum [1,2], to the electron beam. Two solenoids, in opposing directions, are required in order to create the cusped magnetic field in-front of the cathode.

The electron gun was designed to drive multiple microwave sources including two gyro-devices that are currently being experimentally tested at the University of Strathclyde as well as a 390 GHz gyrotron [3]. The gyro-BWO [4,5] and gyro-TWA [6] both use a helically corrugated waveguide [7] interaction region and the cusp gun drives the beam-wave interaction.

The cusp electron gun was numerically optimized [8] using MAGIC, CST Microwave Studio and Opera-3D. Then the gun was built and experimentally tested [9]. We present the results of the simulations and measurements here.

Numerical simulations:
The 3D particle in cell (PIC) code MAGIC was used to numerical simulate and then optimise the electron gun. Desirable electron beam properties include a uniform beam density, minimal off-centering coupled with a low velocity spread. As the gun has to drive multiple gyro-devices it has to operate over a wide range of velocity ratio's, alpha, from 1 up to 3, with a beam current of 1.5 A at an accelerating voltage of 50 kV. The optimised design, at 1.82 T and alpha of 1.65, is shown in Fig 1 with the simulated electron trajectories present. The axial velocity spread ($\Delta Vz/Vz$) was 8% and the alpha spread ($\Delta\alpha/\alpha$) was 10%.

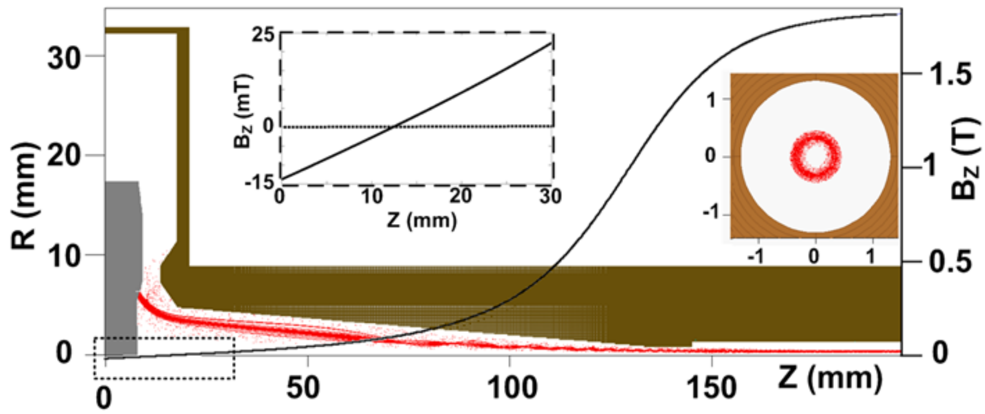

Fig. 1 Optimised electron gun geometry, electron trajectories and magnetic field.

Experimental measurements:
The electron beam voltage, diode current and transported current were measured showing that a 40 kV, 1.5 A electron beam was generated and transported through the beam tube. The cross-sectional shape was then recorded

through a witness plate technique. Through analysis of the profile the alpha value was calculated by knowing the diameter of the electron beam as well as the magnetic field. The measured results were found to be in excellent agreement with the simulated results.

Conclusion:

A 40 kV, 1.5 A cusp electron gun was simulated, optimised, constructed and measured. The optimised gun was simulated to project the desired electron beam with ~8% velocity spread and ~10% alpha spread. The experimentally measured beam results agree well with simulations.

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