Secondary Electron Simulations of a Gyrotron Collector with Magnetic Sweeping and Voltage Depression

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Abstract: *Megawatt-class gyrotrons are designed to distribute the residual electron beam energy across a large collecting surface, to keep power densities low enough to be dissipated without threatening long-term vacuum integrity. Because the incident beam is very narrow, various techniques are used to lower the instantaneous and time-averaged power densities on the collector surface, while keeping the size of the collector within the limits of current fabrication capabilities. Gyrotron collector design typically focuses on optimizing the power deposition of the incident ("primary") beam. It is often assumed that the effects of secondary electron emission from the collector surface (whether due to reflection of primaries, or true secondary emission) will tend to further spread the power density profile. Such additional spreading can be beneficial if it lowers peak power densities, but can be detrimental if it deposits power in undesired locations or sends particles back toward the gyrotron's interaction region. Here, we simulate the effects of secondary/reflected electrons in the VGT-8115, a 110 GHz, 1.2 MW, 10-second gyrotron used for electron cyclotron heating and current drive in the DIII-D tokamak. We examine the ramifications of secondary emission under various operating conditions, such as variations in collector sweeping parameters and collector depression voltage, comparing power densities and particle trajectories with and without secondaries.*

Keywords: gyrotron, collector, electron cyclotron heating, current drive, particle simulation, secondary emission.

INTRODUCTION

The VGT-8115 gyrotron generates a Gaussian 110 GHz beam, with RF output power up to 1.2 MW, and pulse lengths up to 10 seconds. A solid model of the gyrotron is shown in Figure 1. A fraction of the gyrotron's DC electron beam (nominally 94 kV, 45A) is converted to RF, but the remaining power continues into the collector, where it must be safely dissipated. Up to 29 kV of collector voltage depression is used to improve overall device efficiency and lower the incident beam power on the collector surface. Magnetic materials and time-varying magnet coil currents lower the instantaneous and time-averaged power densities, so that the collector can be effectively cooled to maintain vacuum integrity. On surfaces where high incident power densities are expected, CuCrZr is employed to further enhance longevity. All surfaces are actively cooled, with water cooling channels incorporated into the collector structure.

Generally, the power deposition profile of the primary incident beam is assumed to be the most stringent condition, with the highest instantaneous peak power density. Reflected and secondary emission electrons take a portion of the incident power with them, and therefore are assumed to further diffuse the power density profile. Nevertheless, it is possible that such electrons deposit power in unintended locations, or lead to hot spots not evident by considering only the primary beam. Here, we compare the results of simulations with and without the effects of secondary/reflected electrons, for both spent and unspent electron beams, and for a range of depression voltages and beam-sweeping conditions.

BASELINE COLLECTOR DESIGN

Figure 2 shows a comparison of the primary beam trajectories for two different conditions. The upper plot shows trajectories when no magnetic materials are included (i.e., no iron pole-pieces or shields, and no collector coils). In this case, the beam follows the magnetic flux lines of the superconducting magnet, and hits the collector wall in a very narrow region. The lower plot shows the effect of the collector

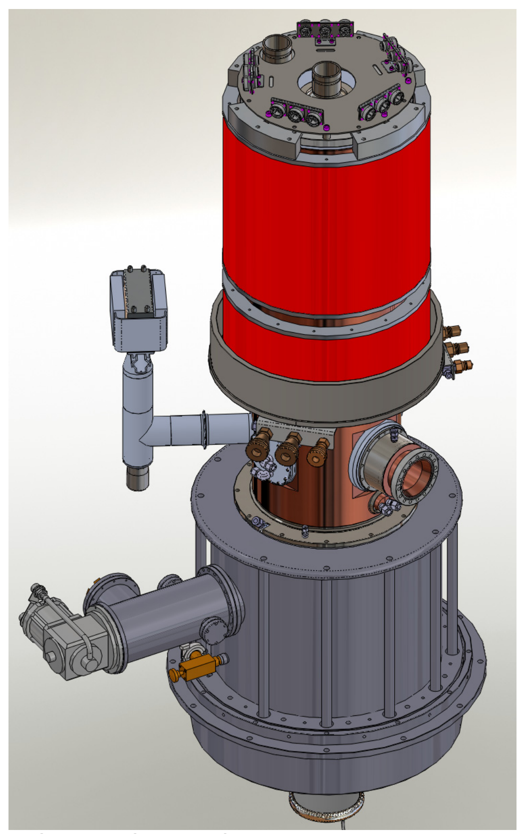

Fig. 1. VGT-8115 Gyrotron Solid Model. The gyrotron is shown installed in its superconducting magnet, with the two collector coils (red) visible around the gyrotron collector.

iron (which broadens the beam as it enters the collector), and shows the effect of the magnetic sweeping (which varies the location at which the beam hits the wall).

Simulations With Secondaries

Figure 3 shows an instantaneous snapshot of simulated trajectories, including two generations of reflected/secondary electrons. As the figure suggests, power is more broadly distributed across the collector surface due to reflected/secondary electrons. Some such electrons are directed back toward the interaction region, although the majority of these are magnetically mirrored, and ultimately return to the collector.

Summary

The examples provided here indicate that secondary electrons tend to lower the predicted power density in the region of primary beam impact, but lead to increased power densities elsewhere. Care must be taken during design and operation of the gyrotron, to ensure that collector power densities do not exceed tolerable values in unexpected locations. In practice, to supplement detailed modeling of the electron trajectories, and thermal-mechanical analysis of the collector, it is recommended that thermal measurements of the collector power distribution be taken during commissioning of the gyrotron, prior to operation at high average power levels, to ensure that operational settings yield acceptable power distributions.

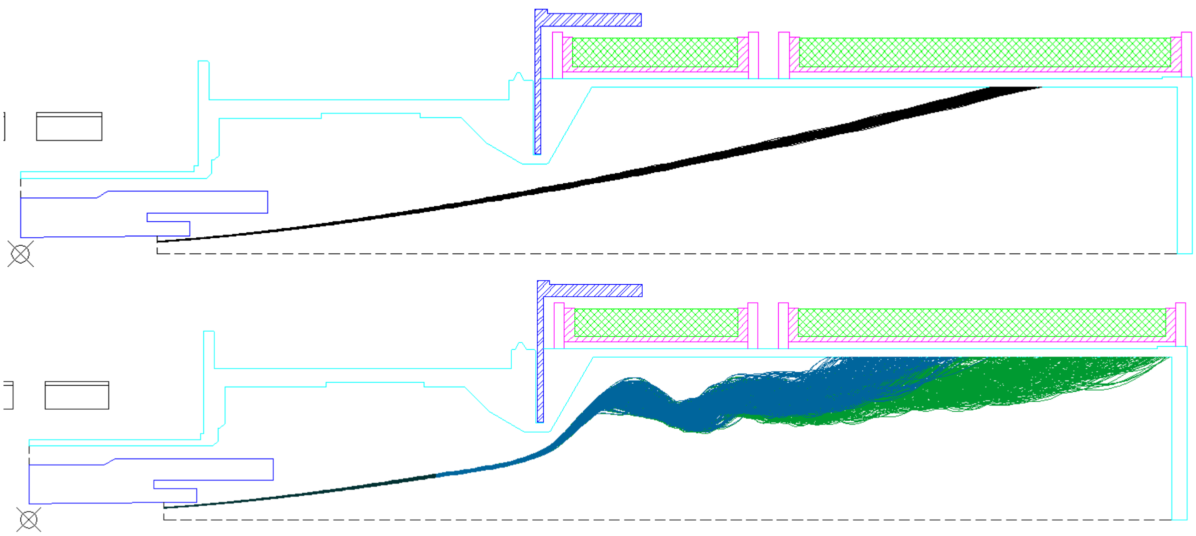

Fig. 2. VGT-8115 Primary Spent-Beam Electron Trajectories. The upper plot shows the predicted trajectories when no magnetic materials or coils are included, other than the superconducting magnet coils. The lower plot shows primary trajectories for the extremes due to sinusoidal sweeping of the upper collector coil.

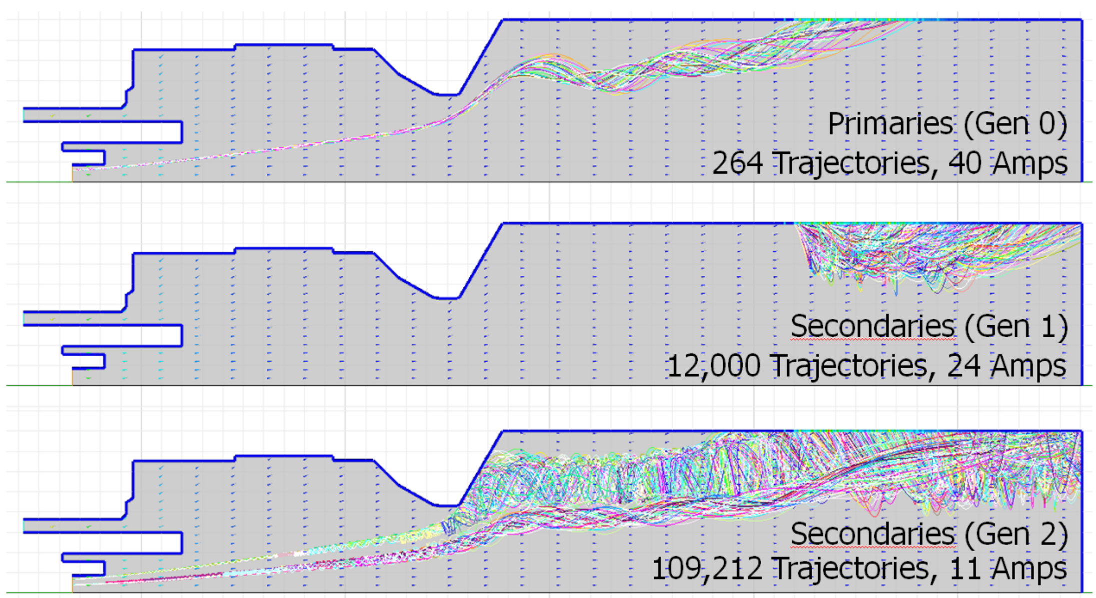

Fig. 3. VGT-8115 Collector Simulation With Secondaries. Each generation is plotted separately, and each plot includes only a subset of the total number of tracked trajectories. The example shown here is for one instant near the bottom of a sinusoidal sweep.