Simulation of Gyrotron Multistage Depressed Collectors using Beam-Shape Transform and E×B Drift

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ABSTRACT

High-power gyrotrons are used for Electron Cyclotron Resonance Heating and Current Drive in nuclear fusion experiments with magnetically confined plasmas. The typical electronic (interaction) efficiency in a gyrotron is around 35 %. With a Single-Stage Depressed Collector (SDC), the power in the rest electron beam can be partly recovered; thus the total efficiency of gyrotrons with SDC can be higher than 50 %. For future fusion power plants, such as the demonstration tokamak DEMO, in order to get sufficient energy gain factor, more power should be recovered from the spent electron beam, the gyrotron overall efficiency should be much higher than 60 % (i.e., collector efficiency > 74 %). Such highly efficient gyrotrons would require Multistage Depressed Collectors (MDCs).

There are generally two kinds of gyrotron MDCs reported in the literature. In the first kind of MDC, rotationally symmetric electric and (non-adiabatic) magnetic fields are tuned which sort the electron beam and spread it directly to the voltage-depressed electrodes [1, 2]. The strong stray field of the gyrotron main magnet confines and guides the primary, as well as the secondary electrons; therefore, the secondary electrons may cause unwanted currents between electrodes which reduce the efficiency or even cause the electrons to be reflected to the cavity and deteriorate the beam-wave interaction. The second concept uses the E×B drift to sort and drift electrons towards the electrodes according to their initial velocities. Even though the principle of this MDCs has been applied in TWTs since 1970s [3], it was not such popular comparing to pure electrostatic TWT-MDCs. This concept has the advantage that it not only solves the sorting of electrons under confining magnetic field, but also drifts the secondary and reflected electrons back to the electrodes. However, the drift cannot be directly used in fusion gyrotrons, since fusion gyrotrons have small-orbit hollow electron beams. Therefore this concept was firstly adapted into gyrotrons in [4], where the drift exists due to the asymmetric electric field synthetized by complicated electrodes, whereas later in [5] the drift is caused by the magnetic field, which requires a strong axial current and is hard to realize. Recently in [6], the parameters and working ranges for the E×B drift used in MDCs are systematically studied, additionally a new idea is proposed, which transforms the hollow electron beam into one or more sheet beams. Afterwards the sheet beams are collected by the E×B drift.

This work reports on the design of MDCs based on the “transform and drift” concept proposed in [6]. The geometry of the MDC and the magnetic field used to transform the electron beam will be proposed. Influence of space charge and secondary electrons will be discussed. 3D simulations with CST shows 85 % collector efficiency with a 5-stage collector.

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