Mechanical Design Study for Gyrotron E×B Drift Two-Stage Depressed Collector

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Abstract: *The key for a significant increase of the gyrotron efficiency is the development of an efficient multistage depressed collector (MDC) for the annular spent electron beam. During the past years, many different design approaches based on E×B drift concept have been theoretically investigated at KIT. The next step towards the experimental validation of such an MDC is the development of a prototype. The complexity of the mechanical design of the MDC is strongly dependent on the size of the electrodes, the manufacturing possibilities of individual parts, the electric field distribution, etc. Considering all those factors, an MDC system has been optimized in order to significantly reduce the manufacturing complexity of the prototype. As a result, a significant smaller and simpler conceptual design for the MDC system is presented.*

Keywords: Gyrotrons; Electron Beams; Magnetic fields; Depressed collector

Introduction

Single stage depressed collectors (SDC) are used in high power gyrotrons to recover energy from the spent electron beam and to reduce the thermal loading on the collector wall. A multistage depressed collector (MDC) is capable to significantly increase the operational efficiency (P_{out}/P_{in}) of a vacuum tube. However, the design of an MDC system for gyrotrons is not trivial due to the fact that the spent electron beam is confined by a relatively strong magnetic field in the collector region. For that reason, the concept of electrostatic sorting as used for TWT and Klystron, is not applicable to gyrotrons. Therefore, a different concept, the separation of the spent beam electrons of a high power gyrotron based on the E×B drift concept was proposed in 2008 [1] and is considered as the most promising method [2-4]. Based on this concept, a systematic investigation of many design approaches based on E×B drift has been conducted during the last years [1, 5-10].

Theoretical Design

The fundamental design of the MDC presented in this manuscript is discussed in Ref. [8] and [9]. The required electric field profile is realized by three helical cuts between the first and second stage of the collector and straight connections between the top and bottom of each helical cut.

In this work, the previously presented collector design is adapted to a 170 GHz 2 MW coaxial-cavity gyrotron, simplified in construction and optimized for production. The magnetic field in the collector region is modified to an almost axial field using additional normal conducting coils, for simplification of the geometry to a cylindrical structure instead of the conical one. This supports also the reduction of the radial dimension of the collector structure. The additional collector coils were designed to fulfill the technical feasibility with compact dimensions and an acceptable power consumption.

Mechanical Design

In the first prototype, a two-stage collector scheme will be designed. The optimal efficiency of a two-stage MDC system depends on the energy distribution of the spent electron beam and the voltage applied on the electrodes. In addition, the deceleration of the first stage must correspond to an energy, which is lower than the kinetic energy of the slowest electron, as it is the case for the SDC, to prevent a reflection back to the cavity. The theoretical optimal collector efficiency without a reflected current versus the depression potentials as function of the applied potential of the two stages is shown in Fig. 1. It should be noted that for the energy distribution the 2 MW coaxial-cavity gyrotron [11] was considered. The red line indicates the maximum theoretical efficiency for any potential applied on the first stage.

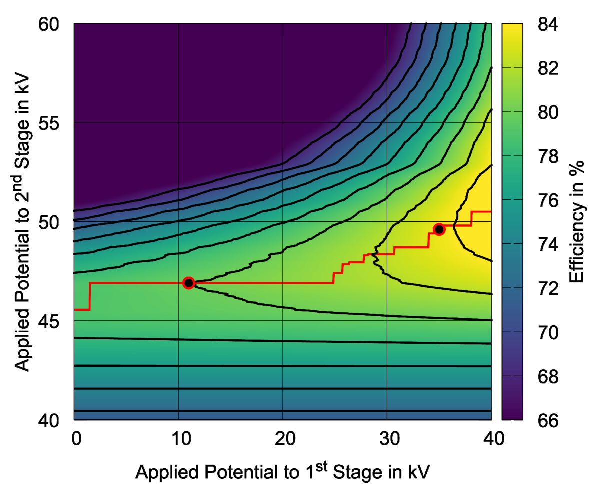

Figure 1. Maximum theoretical collector efficiency without reflections.

The electron drift velocity is increasing with a higher potential difference between the electrodes and with the slope of the helical cut and therefore the length of the E×B region. A voltage of 35 kV at the first stage, which is the same as for the SDC, would result in an optimal voltage of 49.6 kV at the second stage, giving a potential difference of 14.6 kV and up to 83.5 % collector efficiency. On the other hand, a voltage of 11 kV at the first and 46.9 kV at the second stage would result in a potential difference of 35.9 kV and up to 80.0 % collector efficiency. The mechanical designs of two-stage collectors designed each for one of the operation points are shown in Fig. 2. The length of the E×B region can be significantly shorter for the second operation point, keeping the strength of the electron drift in the same order of magnitude. The strength of the drift is also influenced by other factors such as the ratio of the electron beam radius and the inner radius of the collector wall, the width of the helical cut, etc. However, these parameters are fixed for different designs to ensure compatibility of stray magnetic fields, mechanical tolerances and prevention of arcing. The coils needed for the homogenization the magnetic field in the collector region are simpler in the shorter and smaller collector, despite the fact of a stronger magnetic field. The complete length of the collector and the weight of the inner structure are approximately reduced to the half compared to the larger, more efficient variant. The weight and power losses of the collector coils are reduced to 71 %, keeping the current density constant. The inner radius of the collector and the beam radius are reduced to 76 %.

Our effort for the next steps focuses on the smaller and simplified collector design, which is a more attractive choice for the first short-pulse (< 3 ms) prototype.

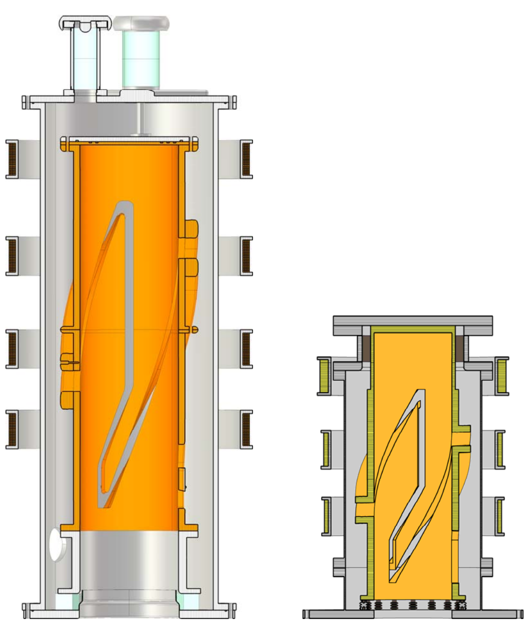

Figure 2. Comparison of a larger and more efficient mechanical collector design versus a smaller and simplified variant.

Conclusion

Two mechanical designs of a cylindrical E×B drift two-stage depressed collector for a 2 MW coaxial-cavity gyrotron were presented and compared in performance and manufacturing complexity. It was found that the overall collector size can be reduced when a reduction of the collector efficiency in the range of 4 % is accepted. The cost and effort of a first two-stage collector prototype are significantly reduced with the simplified design.

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