

Mechanical Design of the Short Pulse $E \times B$ Drift Two-Stage Depressed Collector Prototype for High Power Gyrotron

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Abstract — Multistage depressed collector (MDC) technology is capable of significantly increased overall tube efficiencies of vacuum electronic devices compared to conventional single stage depressed collectors (SDC). The spent electron beam sorting as used for TWT and klystron collectors is not effective in the high stray magnetic field of gyrotrons. For that reason, many new design approaches based on $E \times B$ drift concept have been theoretically investigated during the last years at KIT. The mechanical design for the first MDC for a high power gyrotron is finalized and the production started end of 2020. In this work, the fundamentals of the mechanical design and the cooling principle of the electrodes are presented.

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

I. INTRODUCTION

The energy spectrum of the spent electron beam in high power fusion gyrotrons is widely spread. Only one depression potential is applied in a conventional single stage depressed collector (SDC) with the limitation to the kinetic energy of the slowest spent beam electron. The remaining energy of the decelerated spent electrons is wasted and the collector efficiency $\eta_c = P_{\text{recovered}}/P_{\text{spent-beam}}$ of an SDC is limited to around 60%. The collector efficiency can be significantly increased with a higher number of depression potentials as applied in a multistage depressed collector (MDC) due to the reduced remaining energy of the decelerated spent beam electrons. However, simple axisymmetric MDC concepts are not suitable for separation of the spent beam electrons in high magnetic field flux gyrotrons due to the strong magnetic field in the collector region [1,2]. To overcome the strong confinement of the beam electrons to the magnetic field lines, a different concept is investigated. The $E \times B$ drift concept [3] is considered as the most promising method for a gyrotron MDC and was proposed in 2008 [2,4,5]. Many $E \times B$ drift collector design approaches were systematically investigated during the last years [3,6-12]. The final mechanical design for the first short pulse MDC for a high power gyrotron is based on the design discussed in Ref. [9,10,12].

In the present work, the previously presented theoretical design of a smaller collector was adapted to the magnetic field of the new KIT Tesla gyrotron magnet and the energy distribution of the 170 GHz 2 MW coaxial-cavity gyrotron [13,14]. Compared to the previous design, the initial axial

position was slightly increased and the additional collector coils were adjusted to compensate for the higher magnetic field in the collector region. The cylindrical section of the second electrode was also slightly increased for additional flexibility. The most important dimension data and simulation results are shown in Table I.

TABLE I. DIMENSIONS AND SIMULATION RESULTS

Axial length of the complete collector	1180 mm
Inner radius of the electrode	115 mm
Outer radius of the top flange	235 mm
Depression potential first electrode	11 kV
Depression potential second electrode	46 kV
Maximum power loading density first electrode	< 5 kW/cm ²
Maximum power loading density second electrode	< 3 kW/cm ²
Collector efficiency without secondary electrons	79.5 %
Collector efficiency with secondary electrons	76.1 %

II. MECHANICAL CONSTRUCTION

The mechanical design of the short pulse MDC prototype is axially divided in three sections and in six assemblies. The schematic overview of the complete unit is shown in Fig. 1. The initial section is between the top of the mirror-box and the start of the $E \times B$ region. The main components of this section are the lower assembly for adaptation to the mirror-box and support of the first electrode, the insulators and bottom part of the first electrode as well as different in- and outlets (not shown). The $E \times B$ region, where the spent electron beam is separated in slow and fast electrons, is represented by the middle section of the collector. It is defined between the initial and final axial position of the cut separating the first and second stage. The main components of this section are the rest of the first electrode where all slow electrons are collected, the bottom part of the second electrode, the vacuum envelope and the additional collector coils for homogenization of the magnetic field profile. The final section is located above the $E \times B$ region. The main components of this section are the top cylindrical section of the second stage where the majority of the fast electrons is collected, the top plate of the collector and the insulator of

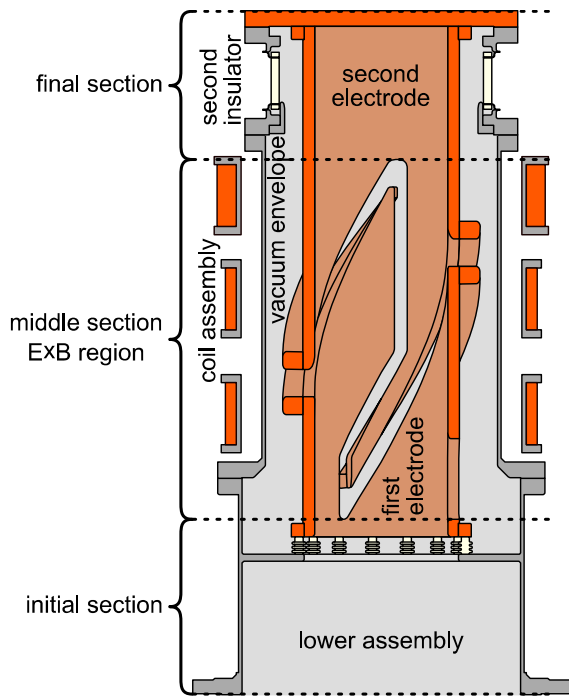


Fig. 1. Short pulse MDC prototype

the second stage. A very high flexibility is given in the mechanical design due to the modularity, which allows exchanging single assemblies easily and cost-efficiently to operate the collector in different magnetic fields and gyrotrons.

III. COOLING

The thermal loading on the collector surface of a 2 MW gyrotron is very high, even for an efficient MDC. The time averaged thermal loading for this short pulse prototype is significantly reduced due to a maximum pulse length of 3 ms in combination with a low duty-cycle in the range of 1 Hz or less. Direct cooling of the heated surfaces is not necessary because of the high thermal conductivity of both copper electrodes, while the averaged thermal loading is relatively low. The second electrode will not be actively cooled in the first experiments, despite the fact that 88 % of the thermal loading in the collector is dissipated here. This electrode is thermally connected to the copper top plate of the vacuum envelope and heat transport to air is possible. The first electrode is thermally isolated by vacuum and the small insulators at the bottom. The heat transport to the

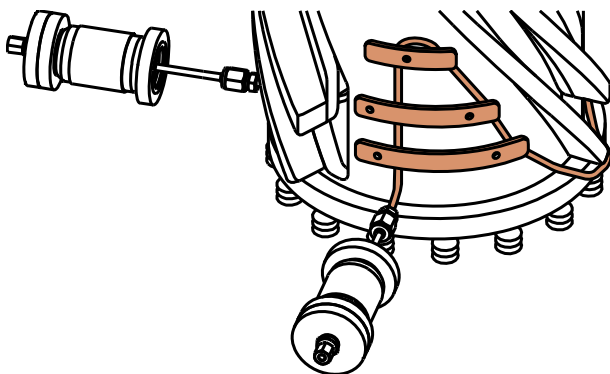


Fig. 2. Cooling loop of first electrode

environment is very limited. A simple water cooling was designed with electrically isolated in- and outlet which are located in the lower assembly. The water pipe is screwed on three sides of the first electrode to provide a sufficient thermal connection. A complete representation of the cooling loop is shown in Fig. 2.

IV. CONCLUSION

The mechanical design for the construction of the first $E \times B$ drift two-stage depressed collector for a 2 MW coaxial-cavity gyrotron was presented. The design is subdivided in multiple modular subassemblies for future modifications and reusability in later studies. The simple water cooling of the first electrode, designed to increase the duty-cycle of the component was also presented. The construction of the first MDC system for the KIT 170 GHz 2 MW coaxial-cavity gyrotron is currently in progress.

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