# Mechanical Design of the Short Pulse E×B Drift Two-Stage Depressed Collector Prototype for High Power Gyrotron

Benjamin Ell [1], Ioannis Gr. Pagonakis, Chuanren Wu, Gerd Gantenbein, Stefan Illy,
Tomasz Rzesnicki, Sebastian Stanculovic, Manfred Thumm, Jörg Weggen and John Jelonnek
Institute for Pulsed Power and Microwave Technology (IHM)
Karlsruhe Institute of Technology (KIT)
Hermann-von-Helmholtz-Platz 1, Eggenstein-Leopoldshafen, 76344, Germany
[1] Corresponding Author (benjamin.ell@kit.edu)

*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*×*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 |
| Maxiumum power loading density first electrode | < 5 kW/cm$^2$ |
| Maxiumum 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

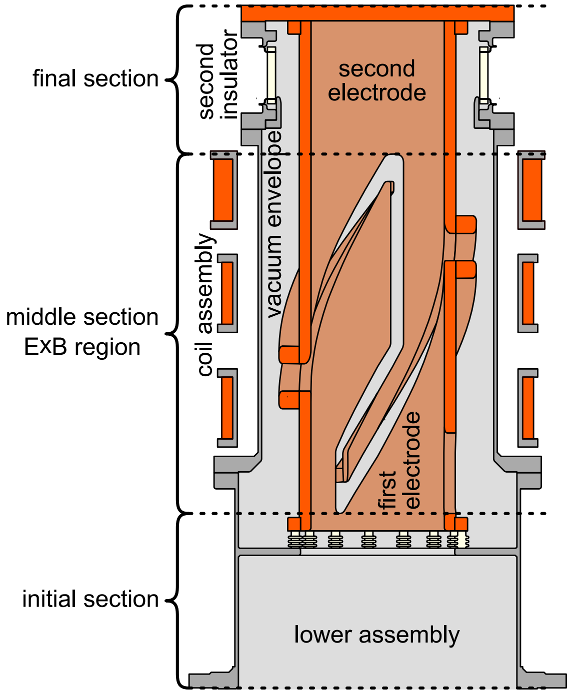

Fig. 1. Short pulse MDC prototype

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 the in 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 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.

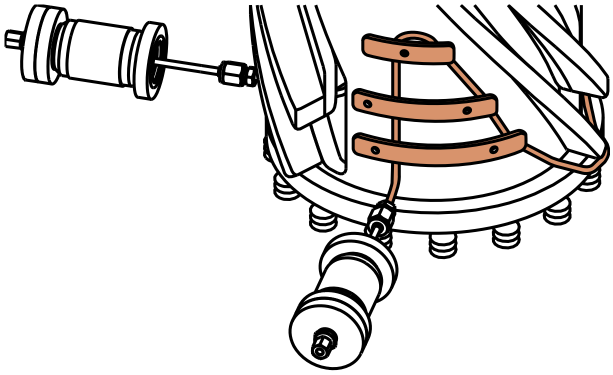

Fig. 2. Cooling loop of first electrode

## 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.

## ACKNOWLEDGMENT

Part of this work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

## REFERENCES

[1] C. Wu, et al., “Preliminary studies on Multistage Depressed Collectors for fusion gyrotrons,” German Microwave Conference (GeMiC), pp. 365–368, 2016.

[2] C. Wu, et al., “Comparison between controlled non-adiabatic and E×B concepts for gyrotron multistage depressed collectors,” EPJ Web Conf. 149, 2017.

[3] I. Gr. Pagonakis, et al., “A New Concept for the Collection of an Electron Beam Configured by an Externally Applied axial Magnetic Field,” IEEE Transactions on Plasma Science 36, 469–480, 2008.

[4] V. Manuilov, et al., “Gyrotron collector systems: Types and capabilities,” Infrared Phys. Technol. 91, 46–54, 2018.

[5] M. Glyavin, et al., “Two-stage energy recovery system for DEMO gyrotron,” in 43rd International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz), pp. 1–2, 2018.

[6] I. Gr. Pagonakis, et al., “Multistage depressed collector conceptual design for thin magnetically confined electron beams,” Physics of Plasmas 23, 043114, 2016.

[7] C. Wu, et al., “Novel multistage depressed collector for high power fusion gyrotrons based on an E×B drift concept,” in 18th International Vacuum Electronics Conference (IVEC), 2017.

[8] C. Wu, et al., “Conceptual designs of E×B multistage depressed collectors for gyrotrons,” Physics of Plasmas 24, 043102, 2017.

[9] C. Wu, et al., “Gyrotron multistage depressed collector based on E×B drift concept using azimuthal electric field. I. Basic design,” Physics of Plasmas 25, 033108, 2018.

[10] C. Wu, et al., “Gyrotron multistage depressed collector based on E×B drift concept using azimuthal electric field. II: Upgraded designs,” Physics of Plasmas 26, 013108, 2019

[11] B. Ell, et al., “Coaxial Multistage Depressed Collector Design for High Power Gyrotrons Based on E×B Concept,” Physics of Plasmas 26, 113107, 2019.

[12] B. Ell, et al., “Mechanical Design Study for Gyrotron E×B Drift Two-Stage Depressed Collector,” in 21st International Vacuum Electronics Conference (IVEC), 2020

[13] T. Rzesnicki, et al., “2.2-MW record power of the 170-GHz european pre-prototype coaxial-cavity gyrotron for ITER,” IEEE Transactions on Plasma Science, Vol. 38, No. 6, pp. 1141-1149, 2010.

[14] S. Ruess, et al., “KIT coaxial gyrotron development: from ITER toward DEMO,” Int. J. of Microwave and Wireless Technologies, 10, 547-555, 2018.