1.5 MW, 140 GHz Gyrotron for W7-X
- development status and experimental results -

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***Abstract*— For the upgrade of the Electron Cyclotron Resonance Heating (ECRH) system of the stellarator Wendelstein 7-X (W7-X), a 1.5 MW, 140 GHz continuous-wave (CW) gyrotron is under development. In order to provide a first experimental verification of the scientific microwave and electron beam optics design of the gyrotron at pulse lengths of a few milliseconds (ms), Karlsruhe Intitule of Technology (KIT) has developed and tested successfully a short-pulse pre-prototype gyrotron. The tube was stably operated at up to 1.6 MW output power. The status of the project as well as the results achieved during the first experimental campaign, are presented in this paper.**

I. INTRODUCTION

The upgrade of the ECRH-System of W7-X is planned with the development of a Continuous-Wave (CW) 1.5 MW, 140 GHz prototype gyrotron, which will be followed by another three industrial tubes. In order to mitigate the development risk and cost, the design of the 1.5 MW tube bases on the existing 1 MW W7-X gyrotrons (TH 1507) of our industrial partner Thales, France. In order to support the development of the 1.5 MW CW gyrotron and to validate the scientific RF and electron beam optics design, a modular short-pulse (SP) pre-prototype gyrotron was built and tested at KIT, which shares the same scientific design with the CW prototype. For achieving the 1.5 MW level some improvements of the existing TH1507 design were necessary. The cavity was optimized for a higher order mode to bring the interaction efficiency close to the theoretical maximum and allow up to 1.5 MW output power operation with tolerable losses in the cavity wall. Furthermore, due to the higher electron beam current required to deliver 1.5 MW power, a modification of the beam tunnel was necessary. It allows to reach a higher suppression efficiency against the excitation of parasitic modes.

II. RESULTS

In the first experimental campaign in 2020 with the short-pulse (SP) pre-prototype tube (Fig. 1) it was possible to find a wide range of operating parameters that delivered at least 1.5 MW of output power in ~1 ms pulses, without exciting parasitic oscillations [1]. However, in order to avoid parasitics, the calculated pitch factor α of the electron beam remained below 1.1 in most experimental shots, with $\alpha = 1.2$ being the nominal design value. Therefore, in the second experimental campaign in 2021, the 140 GHz 1.5 MW SP gyrotron was equipped with a modified beam tunnel that contains a new type of damping ceramics. The experimental results show that the modified beam tunnel equipped with this new type of ceramics performs better for higher beam currents, which is the region of greater interest. Nevertheless, this does not impede the target for efficient, parasitic-free 1.5 MW operation. The full set of results achieved at nominal and at slightly modified magnetic field values in the cavity region are presented in the figures Figs. 2 and 3 respectively. In parallel, the performance of the new quasi-optical output coupler of the gyrotron has been assessed through high-power measurements. It has been confirmed that the Gaussian mode content of the gyrotron is higher than 97.7 %, which is in excellent agreement with the low-power measurements as well as with the simulation. Furthermore, the gyrotron was operated with a collector depression voltage in order to ensure that there is no limitation after the modification of the beam tunnel. During the tests the generated output power was 1.6 MW and a maximum efficiency of 43 % was demonstrated. This performance is slightly better than the best one obtained with the baseline beam tunnel (1.5 MW, 44 %, 1st campaign). The achieved results of depressed collector operation at the nominal and slightly tuned cavity magnetic field are presented in Fig. 4.

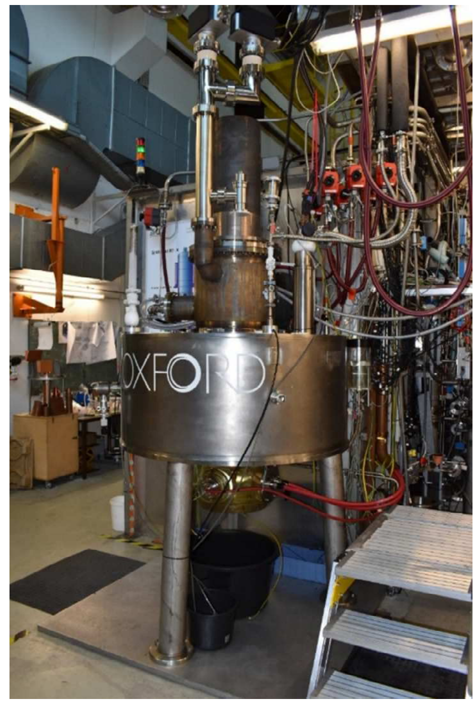

Fig. 1. 1.5 MW, 140 GHz short-pulse pre-prototype gyrotron at KIT

III. SUMMARY

Following the successful tests with the short-pulse tube, the complete design of the 140 GHz 1.5 MW CW prototype gyrotron has been finalized. The gyrotron is expected to be delivered to KIT in the first half of 2022. Long-pulse tests with the CW prototype tube are planned in the third quarter of 2022. In anticipation of these experiments, the KIT teststand FULGOR is under preparation.

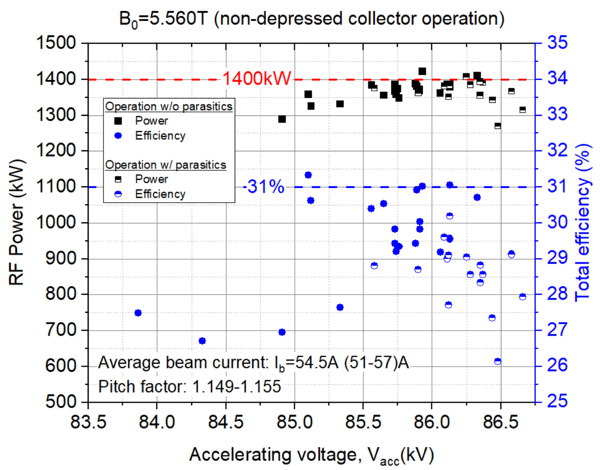

Fig. 2. Operation at the nominal magnetic field B_0 = 5.560 T.

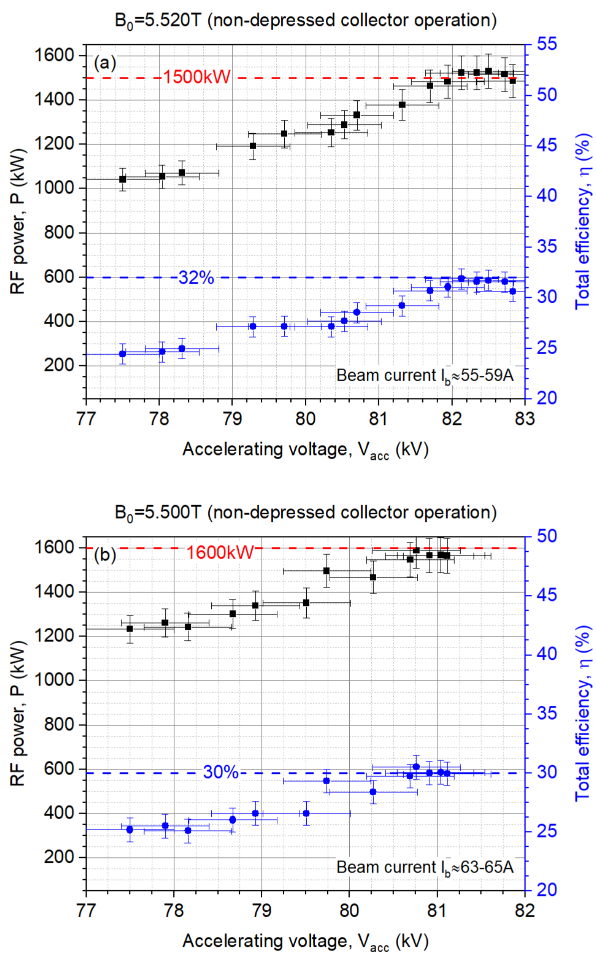

Fig. 3. Operation at lower magnetic field (a) 5.520 T and (b) 5.500 T.

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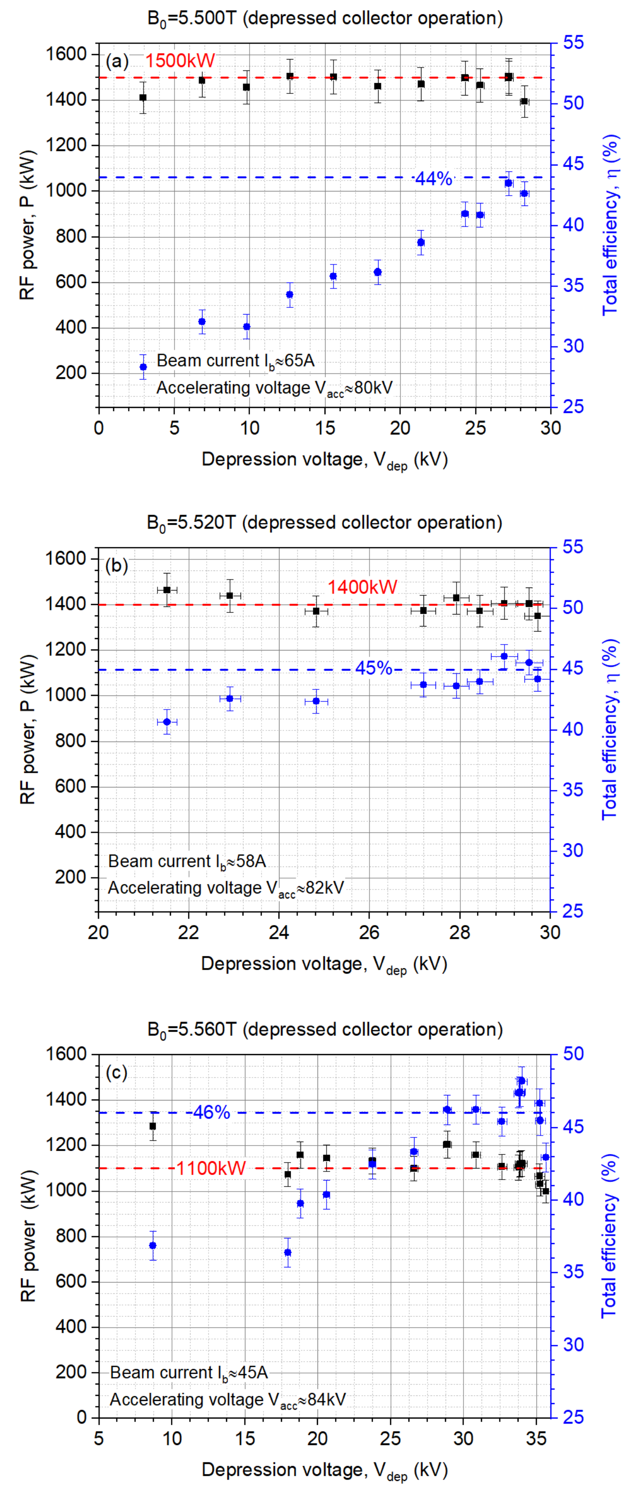

Fig. 1. Depressed collector operation at magnetic field (a) 5.500 T, (b) 5.520 T and (c) 5.560 T (nominal).

REFERENCES

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