A computer-controlled low-power RF system to generate very high-order modes used in future fusion gyrotrons

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Fusion plasma applications require a very powerful heating system to achieve the required high plasma temperatures. Gyrotrons are the only RF sources known today which are capable to produce the megawatt-level RF output power at continuous waves (CW) in the mm-wave range for Electron Cyclotron Heating and Current Drive (EC H&CD). For the stellarator W7-X at IPP Greifswald, Germany [1] the EC heating system is operating at 140 GHz already. The ITER tokamak, France [2] will operate at an even increased frequency of 170 GHz. For the planned DEMOnstration fusion power plant (DEMO) and the following future Fusion Power Plant (FPP) the current drive frequencies are expected to be above 200 GHz [3]. Even more, the RF output power is expected to increase from 1 MW for ITER to minimum 2 MW for DEMO. To operate at that high frequency and RF power the gyrotron will have to operate in a very high-order cavity mode. The excitation of those very high order modes and the mode separation from the different possible competing modes is challenging in the cavity design. An even more difficult challenge exists for the excitation of the very high order mode using a low-power RF test system. In latter case, the electron beam is missing which is mainly responsible for the transverse mode selection. Nevertheless, the availability of such a low power test system is vital in the gyrotron design and validation. That is particularly valid for the launcher of the quasi-optical output coupler, which converts the rotating high-order operating cavity mode into a linearly polarized Gaussian output beam. At KIT, the existing test set-up includes a quasi-optical mode generator and a purely manual sliding unit to adjust the relevant elements. The excitation of the correct operating mode is an extremely time consuming task which is not always successful. Additionally, the set-up is limited up to frequencies of 170 GHz so far due to the implemented frequency multiplier and harmonic mixer in the low power RF generation and reception. The novel test system which has been developed allows the fully automated adjustment of the critical geometrical parameters by an advanced computer controlled system. Additionally, it allows to operate at much higher frequencies up to 330 GHz. In addition to that, in total five different mode evaluation techniques have been implemented. Two of them are used to determine the azimuthal and radial indices of the mode. The other three procedures are helping to evaluate the quality of the excited mode.

The new RF test system has been already tested. In a first step, a 140 GHz $TE_{28,8}$-cavity mode which is the mode used in the W7-X 1 MW CW gyrotrons has been excited successfully. In a second step, a mode generator for the $TE_{28,10}$/$TE_{36,12}$-cavity modes operating at 140/175 GHz has been designed and successfully tested. For the design the scattering matrix code described in [5] was used. Using the advanced measurement system, the quality of the excited modes has been significantly improved. The time for the proper adjustment has been reduced by a factor of 10.

[1] H. Braune, *et al*., in Proc. IRMMW, Copenhagen, Denmark, Sep. 2016, pp. 1-2.
[2] T. Omori, *et al*., Fusion Eng. Des., (2011).
[3] G. Federici, *et al*., in Proc. 25th SOFE, (2013).
[4] K. A. Avramidis, *et al*., EC 20, Greifswald, Germany, May 2018.
[5] D. Wagner, *et al*., Int. J. Infrared and Millimeter Waves **19**,185-194 (1998).