Development of the Multi-physiCs tool for the integrated simulation of the Cavity and its application for the design of gyrotron cavities for thermonuclear applications

By

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Abstract

High-power gyrotrons, used in tokamaks and stellarators for electron cyclotron resonance heating and current drive, should deliver a microwave power of the order of MW per unit, at frequencies above 100 GHz, to sustain the plasma conditions during the fusion reactors operations for the production of electrical power. The ohmic load, produced by the interaction between electrons beam that moves inside the central hollow region of the resonator and the magnetic field, is deposited on the inner wall of the resonant cavity and it constitutes one of the major technological factors which limits the gyrotron operations conditions. A forced flow of pressurized water is used to cool down the cavity structures to reduce the temperature and, consequently, to minimize the deformation of the resonating surfaces.

In the frame of the EUROfusion activities the MUlti-physiCs tool for the integrated simulation of the CAvity (MUCCA) has been developed in the collaboration between Politecnico di Torino (PoliTo), Karlsruhe Institute of Technology (KIT), Fusion for Energy (F4E) and Thales Electron Devices (TED), since 2016. The MUCCA tool includes thermal-hydraulic, thermo-mechanical and electro-dynamic simulations in an iterative self-consistent procedure applied to compute the gyrotron cavity behaviour, aiming at evaluating the modification of the operating conditions of the component. The MUCCA tool is applied in this work to different cavity layouts in order to present the characteristics of the simulation tool and to show the wide range of its application for the development the cooling aspects of the gyrotron cavities.

The tool is successfully validated comparing the computed results with those from the experimental test campaigns performed on the cavity designed for the 170 GHz, 1 MW gyrotron developed for ITER electron cyclotron system. In this cavity layout, the Raschig Rings (RRs) cooling structure is used as a heat transfer promoter to reduce the temperature inside the resonator. On the same cavity structure, an alternative cooling configuration, involving a set of parallel semi-circular Mini-Channels (MCs), is proposed and optimized to improve the thermal behaviour of the cavity aiming at reducing the temperature peak computed in the most critical region of the resonating region of the cavity.

In DEMO perspective, the MUCCA tool is used to evaluate the evolution of the coaxial cavity, currently under development with an annular cooling strategy for the 170 GHz, 2 MW gyrotrons. In order to improve the performances of the gyrotrons to be used in the DEMO electron cyclotron system, the layout of the cavity is designed at KIT including the coaxial insert, which is also modelled in the simulations. The computed results highlight the necessity to optimize the preliminary annular cooling configuration proposed, since the temperature peak obtained with the present annular cooling configuration overcomes in ~150 ms the limits defined for the safe gyrotron operation conditions. As performed in the analysis of the cavity for the 1 MW gyrotrons, an explorative simulation is performed applying a set of parallel circular MCs as cooling promoter strategy, which improve considerably the cooling behaviour of the cavity with respect the annular cooling design.