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Design, Test and Analysis of a Gyrotron Cavity Mock-up cooled using Mini-Channels

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The cooling enhancement of the water-cooled resonance cavity in the design of the European 170 GHz, 1 MW gyrotron for ITER, where the peak heat flux can reach 20+ MW/m², albeit on a very short (˜ 1 cm) region, is currently based on the Raschig Rings technology. As an alternative to that, mini-channels drilled in a copper annulus have been recently proposed, also based on Computational Fluid Dynamics (CFD) analysis, which demonstrated that this solution could reach higher cooling performance than other possible alternatives: the high Reynolds number mainly due to the high fluid speed in the mini-channels, in fact, guarantees a high heat transfer coefficient, with local boiling occurring in the peak load region. However, the CFD model suffers from several uncertainties related to the presence of free parameters in the boiling model, implemented in the commercial tool STAR-CCM+, adopted in the simulations, and an experimental proof of the cooling capability of the mini-channel configuration was needed.

In 2016, a planar mock-up using the mini-channels cooling option, fully relevant for the cavity operating conditions, was first designed, based again on CFD analysis, then built by Thales Electron Devices and eventually tested at the Areva premises at Le Creusot (France).

The mock-up is made of Glidcop®, a copper-based alloy also used in the construction of the full size gyrotron cavity. An electron gun with a 28 mm x 28 mm square shaped footprint was used to heat the target region of the mock-up. The mock-up was equipped with 9 thermocouples anchored at different heights above the heated surface; the test facility was equipped with a pyrometer, pointing at the middle of the mock-up heated surface, and with an infra-red camera, both dedicated to the measurement of the target surface temperature. A flowmeter, and the pressure taps at the mock-up inlet and outlet completed the test setup. The test matrix included tests at four different mass flow rates, exploiting a large range of power density up to ˜ 30 MW/m².

In the paper, the test results are first presented and discussed, with particular reference to the reliability of the surface temperature measurements and to the heat removal capability of the mini-channel cooling configuration. Coming to the comparison with the CFD model results, the available dataset at low heat fluxes, where boiling is not present in the simulations, is used to confirm the suitability of the turbulence model adopted in the simulations. A second subset of the experimental data is then used to calibrate the CFD model when the boiling regime is entered, and the model results are validated against the rest of the database at high heat fluxes. This calibration/validation exercise allows obtaining a reliable numerical tool, which will be used for the simulation of the full-size gyrotron cavity operation, to assess predictively the benefits of this cooling option with respect to that currently adopted.

Eligible for student paper award?

No

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