Contribution ID: **362** Type: **Poster**

Prototype design of a 700 C in-vacuum blackbody source for in-situ calibration of the ITER ECE diagnostic*

Wednesday 7 June 2017 13:40 (2 hours)

Two blackbody sources permanently located within the ITER Diagnostic Shield Module (DSM) at equatorial port 9 will operate in conjunction with two remotely retractable mirrors to generate and direct blackbody radiation to calibrate the radial and oblique views of the ITER Electron Cyclotron Emission (ECE) diagnostic. The main calibration requirements include a high-emissivity surface heated to 700 C, 5000 hours operational lifetime over 20 years, and ability to perform the calibration in the presence of a magnetic field. Major design drivers include a heater current limit of 40 A, no direct fluid cooling to mitigate failure risks, small size to avoid compromising neutron shielding, and adequate structural support to mitigate vibration loads.
Each calibration source consists of an engineered emissive surface to generate the blackbody emission, a heating element to control the temperature of the emissive surface, heat shields, housing, power cables, and temperature sensors for feedback control. Early R&D focused on the heater and started with a commercial-off-the-shelf Inconel heater. After extensive testing, temperature limits, long term emissivity instability, and material vaporization issues prompted consideration of alternative heaters. A second focus was on efficient transfer of the heat to the emissive surface. When heated from its flat side to 965 C by an open molybdenum wire, a molybdenum plate with machined V-grooves to increase its effective emissivity was found to successfully raise the temperature of the emitter to the required 700 C. Further testing demonstrated long term stability exceeding 120 hours of continuous operation at 700 C and under high vacuum. These results led to a custom encapsulated molybdenum heater designed in close collaboration with a heater manufacturer. Mechanical support of the silicon carbide emitter presented challenges due to brittleness of ceramics. Thermal expansion, material strength degradation at high temperature, and restrictions on materials allowed in ITER required several design iterations to arrive at an acceptable emitter support solution. Heat management in the hot calibration source also presented challenges because of the goal to avoid direct fluid cooling. While excess heat is allowed to be transferred to the cooled DSM wall, which is separately maintained at 100 C, a calibration source attachment approach that results in adequate heat transfer proved challenging to achieve. Finally, a closed-loop temperature control approach was developed, implemented, and successfully tested where the emitter temperature was regulated to within 0.5 C.
Description of the preliminary design of the hot calibration source with supporting analyses and test results will be presented in the paper.

*This work is supported by US DOE Contract No. DE-AC02-09CH11466. All US activities are managed by the US ITER Project Office, hosted by Oak Ridge National Laboratory with

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Session Classification: W.POS: Poster Session W

Track Classification: Diagnostics and instrumentation