

Short Pulse Optimization of High Heat Flux Testing for Plasma Facing Components in the Fusion Devices

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1. Introduction

Plasma facing components (PFCs) for fusion devices such as ITER and DEMO are exposed to the heat loads of up to several tens of MW/m² and the repeated intense transient events on a millisecond time scale, represented by radiation flash events and ELM-like loads [1,2]. Performance verification of tungsten PFCs relies on dedicated high heat flux test (HHFT) facilities, among which electron beam devices are the established for the thermal fatigue and thermal shock testing [1,3]. Recent qualification specifications require that the facility demonstrate the controlled heat loads with a reproducible, defined waveform of beam power together with quantified diagnostic performance. This paper presents the short pulse operation optimization and the diagnostic system design of the KAERI high heat flux test facility toward such verification testing of W PFC mockups.

2. Methods and Results

2.1 Short Pulse Operation Optimization

The target envelope is cyclic short pulse loading at a power density of up to 0.20 GW/m² with a 1.2 msec rectangular or 2.4 msec triangular waveform over a 30 × 30 mm² loading area for 100 cycles each. The surface temperature must be recovered below 300 °C before every cycle, and no indication of delamination of the coating is the acceptance criterion.

The short pulse operation was optimized in three steps. First, the achievable peak power density was mapped as a function of beam power, spot size, and focusing conditions to identify the operating window that reaches 0.20 GW/m². Second, reproducible millisecond waveform generation was established through beam switching and fast deflection control, and the performance for rectangular and triangular waveforms was assessed against the waveform requirement. Third, transient thermal analyses of uncooled specimens were performed to derive the dwell time needed to recover the initial temperature criterion under jig conduction and natural cooling.

2.2 Diagnostic System Design

Short pulse testing at millisecond time scales imposes acquisition rate and temperature range requirements that exceed conventional facility instrumentation. The designed diagnostic system therefore combines a fast pyrometer of two-color type (up to 2,000 °C, acquisition rate ≥ 10 kHz) with an infrared camera for the distribution of surface temperature (200 ~ 1,500 °C, acquisition rate ≥ 10 Hz). The two-color configuration was selected because of the cancellation of the emissivity, which is essential for tungsten surfaces whose effective emissivity evolves significantly under beam exposure [1,3]. The temperature diagnostics are supported by heat load recording at ≥ 10 kHz for the short pulse.

3. Conclusions

Short pulse operating scenario and a diagnostic system for the HHFT facility were designed against qualification requirements for W PFC mockup in the fusion devices. The optimization links beam parameters, waveform control, and transient thermal response into a single operating envelope, while the two-color-pyrometer-based fast diagnostic set provides emissivity tolerant surface temperature measurement at the required 10 kHz rates. Verification of the designed conditions on instrumented mockups and quantification of the remaining gap toward full millisecond short pulse capability are in progress and will be reported.

REFERENCES

- [1] Ch. Linsmeier, B. Unterberg, J. W. Coenen, R. P. Doerner, H. Greuner, A. Kreter, J. Linke, H. Maier, "Material testing facilities and programs for plasma-facing component testing," *Nuclear Fusion* 57 (2017) 092012.
- [2] J. Linke, J. Du, T. Loewenhoff, G. Pintsuk, B. Spilker, I. Steudel, M. Wirtz, "Challenges for plasma-facing components in nuclear fusion," *Matter and Radiation at Extremes* 4 (2019) 056201.
- [3] P. Majerus, R. Duwe, T. Hirai, W. Kühnlein, J. Linke, M. Rödiger, "The new electron beam test facility JUDITH II for high heat flux experiments on plasma facing components," *Fusion Engineering and Design* 75–79 (2005) 365–369.