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Predictive Maintenance in Fusion Devices: Estimating the Remaining Useful Life of Plasma-Facing Component Units Using a Similarity-Based Approach

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With a view to reliability, availability, maintainability, and inspectability (RAMI) for DEMO, achieving an availability of 30-60\% while minimizing unscheduled shutdowns is a critical prerequisite [1]. Plasma-facing components (PFCs), such as the divertor and first wall, are exposed to extreme thermal loads, shocks, and particle bombardment, conditions that can lead to component failure. In future fusion reactors, such failures may severely compromise plant availability, triggering costly remote maintenance interventions that typically last several weeks, resulting in substantial operational disruption directly impacting the final price of electricity. Predictive maintenance addresses these challenges by enabling proactive scheduling based on estimates of the remaining useful life (RUL) of components, derived from historical sensor data. However, monitoring PFCs in real time is constrained by limited diagnostic access, and full-scale modelling of reactor conditions is computationally prohibitive. In this study, we propose a similarity-based method for RUL estimation of beryllium tiles under steady-state heat loading from an electron beam [2]. Texture features including gray level co-occurrence matrix, local binary pattern, and fast Fourier transform are extracted from infrared images to capture the evolution of local pixel intensity patterns in the hottest surface regions and are fused into a health indicator. The RUL is then inferred by comparing the current health trajectory to those of previously observed tiles and interpolating from the most similar cases. This data-driven approach does not rely on a physical degradation model, making it particularly suited for conditions where failure mechanisms are complex or poorly understood. Although demonstrated under controlled conditions, the method is potentially extensible to more complex damage in real machine operations.

[1] Maisonnier, D. (2018). RAMI: The Main Challenge of Fusion Nuclear Technologies. Fusion Engineering and Design, 136, 1202–1208

[2] Hirai, T., Ezato, K., & Majerus, P. (2005). ITER Relevant High Heat Flux Testing on Plasma Facing Surfaces. Materials Transactions, 46(3), 412–424

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