Real-Time Temperature Control and Performance Optimization of an Induction Heating System for In-Situ Neutron Experiments

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Abstract

Induction heating is an indispensable non-contact heat source for advanced thermal manufacturing and in-situ high-temperature characterization, yet conventional low-/mid-frequency systems suffer from large skin depth and diffuse energy deposition, resulting in sluggish heating that fails to meet the demands of rapid and highly localized thermal processing. To overcome this limitation, we propose a "high-frequency–high-current" synergistic intensification strategy: the inverter frequency is elevated to the hundred-kHz range and paired with a large-current ZCS-IGBT series-resonant converter, compressing electromagnetic energy into a sub-millimetre surface layer and enabling a quadratic escalation of heat-flux density and an extreme heating rate. A full-digital phase-locked loop together with dual-redundant protection guarantees stable high-current output at elevated frequencies. Theoretical analysis, multi-physics simulations and comparative experiments consistently demonstrate that the strategy can rapidly and uniformly heat the work-piece surface to the target temperature, offering an efficient, controllable and mobile heat source for low-carbon and precision thermal treatments.