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Swirl tube design of the pole shiled in the magnet for the long pulse upgrades of EAST-NBI based on the subcooled boiling

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Neutral Beam Injection (NBI) auxiliary heating system for Experimental Advanced Superconducting Tokamak (EAST) designed with the design of the 180 degree magnetic field deflection to deflect the un-neutralized particles during beam transmission. In order to protect against the divergent beam, the copper pole shields are placed on both sides of the neutral beam in front of each deflection magnet. For future planned EAST-NBI operation with longer beam pulse lengths (more than 100 s to 1000 s) and higher beam power (2˜4 MW), heat density will be more than 10 MW/m2 deposited on each shield, so it is very important to enhance the heat transfer of shields to ensure their good working performance and even the safety operation of NBI system. In this paper, based on the analysis of the heat transfer performance of the initial structure of the EAST-NBI deflection magnet pole shield, the heat transfer enhancement design with swirl tape inserts of cooling tube is proposed, called swirl tube. Considering the heat flux distribution mechanism of Rensselaer Polytechnic Institute (RPI) model, interfacial mass transfer, interfacial momentum and energy transfer and the empirical relation of void fraction, combined with Eulerian two-phase flow and heat transfer control equations, the calculation method and flow chart of subcooling boiling was improved. Then the thermo-flow-solid coupling analysis has been done to the pole shield structure with swirl tubes, and the performance optimization of its key structural parameters was completed according to the operation limitation of the pole shield and its cooling water system. The heat transfer performance of the final structure was analyzed and checked well meeting the design requirements. This study is a theoretical basis of the experimental design of heat transfer enhancement structure for the pole shield in EAST-NBI system, and provides a reference for the heat transfer enhancement design of other high-heat-flux components in the EAST-NBI system, so it has a very important theoretical and practical significance for future long pulse and high power operation.

Keywords—Neutral beam injection, High heat flux components, Swirl tube, Heat transfer enhancement, Thermo-flow-solid coupling analysis

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