Contribution ID: **101** Type: 口头报告

高温气冷堆模拟机分相流蒸汽发生器模块开发及分析

摘要

清华大学核研院针对模块式高温气冷堆开发了工程模拟机（HTR-ESS），已成功用于 HTR-PM 操纵员培训、运行特性分析、方案设计等工作。为拓展 HTR-ESS 模拟紧急停堆后蒸汽发生器内的气液分层现象以及再启动过程的能力，开发了分相流换热管模块 TFNet，并建立了高温气冷堆螺旋管直流蒸汽发生器的模型 TFNet-SG。通过多种节点划分方案的比较和分析，综合考虑计算精度与实时性，明确了 100 节点的模型。通过稳态工况分析确认了模型的合理性及准确性，并在此基础上模拟了紧急停堆过程，分析了不同操作对蒸汽发生器内部参数的影响。后续准备将 TFNet-SG 嵌入模拟机完整系统，开展正常运行、紧急停堆、再启动等全过程模拟。

关键词

高温堆模拟机；直流螺旋管蒸汽发生器；紧急停堆；分相流流网

Abstract

The Institute of Nuclear and New Energy Technology (INET) at Tsinghua University has developed an Engineering Simulator, HTR-ESS, specifically for Modular High-Temperature Gas-cooled Reactors (HTR), which has been successfully employed in operator training, operational characteristic analysis, and operational scheme design for the HTR-PM project. To expand the ability of HTR-ESS to simulate gas-liquid stratification phenomena and restart processes in the steam generator after the SCRAM, TFNet (Two-fluid Flow Network module) was established on the vPower platform. And TFNet-SG is specially developed from TFNet for helical tubes in HTR. Real-time thermal-hydraulic models of the steam generators have been established with various node division schemes. A nodes division scheme with 100 nodes has been selected for computational accuracy and real-time performance. The accuracy of the inlet and outlet parameters in steady-state conditions and the rationality of the internal parameter distribution have been confirmed by comparing the new steam generator models with the experimental data and design parameters. The results indicate that the difference between the calculated values, experimental data and design parameters of the steam generator model constructed by TFNet-SG is relatively small in 20%, 30%, 50%, 75% and 100% power conditions. And the variation trend of heat transfer coefficients and heat flux density calculated using TFNet-SG aligns more closely with actual physical processes compared to the original simulated steam generator module tools utilized in HTR-ESS. Furthermore, dynamic processes of the SCRAM have been simulated based on the 100% power steady-state condition with different operations of valves closure and flow flux reduction speed. The calculation results indicate that a shorter closing time interval between the main steam valve and the main feedwater valve will lead to a faster increase in internal pressure within the steam generator. Longer flow flux reduction time leads to extended heating time on the steam-water side and higher overall temperature of the steam generator. Future work will involve connecting TFNet-SG with other systems in the secondary loop of the simulator, coupling it with the primary loop for calculations, and conducting simulation analysis of the SCRAM to the restart process for the HTR-PM power plant.

Keywords

HTR Simulator; Steam generator; SCRAM; Two-Fluid flow network

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Session Classification: 核技术与应用、医学物理与工程

Track Classification: 03 口头报告: 核技术与应用、医学物理与工程