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清华高通量堆全堆输运计算 **GPU** 加速研究

摘要

为提高清华高通量堆（THFR）全堆中子输运计算效率，充分利用单机 CPU-GPU 异构系统的计算资源，研究并实现了三维中子输运计算全流程的 GPU 加速。全堆输运计算基于 2D/1D 方法，径向采用二维特征线方法（MOC），轴向采用一维 MOC，并实现了三维粗网有限差分（CMFD）加速。通过 C5G7 3D 扩展基准题和 THFR 3D 简化模型进行精度验证和效率分析，使用单块 NVIDIA 3090 GPU 和采用 32 核并行及 SIMD 向量化并行的 CPU 进行计算。结果表明：GPU 计算精度良好，完全单精度适用于全堆输运计算；C5G7 3D 扩展基准题的计算加速比达到 40 倍以上，THFR 3D 简化模型的计算加速比达到 5.6 倍，计算效率大幅提升。

关键词

高通量堆；中子输运计算；2D/1D 方法；GPU

Abstract

To improve the efficiency of whole-core neutron transport calculations for Tsinghua High Flux Reactor and fully utilize the computational resources of single-machine CPU-GPU heterogeneous systems, the GPU acceleration of entire three-dimensional neutron transport calculations has been studied and implemented. Whole-core transport calculation is based on the 2D/1D method, and the radial calculation employs the two-dimensional method of characteristics(MOC), while the axial calculation uses one-dimensional MOC, and three-dimensional coarse mesh finite difference(CMFD) acceleration has been implemented. Accuracy verification and efficiency analysis were performed using the C5G7 3D extension benchmark and the THFR 3D simplified model, with computations carried out on a single NVIDIA 3090 GPU and a CPU utilizing 32-core parallel processing and SIMD vectorization. The results indicate that the GPU achieves good computational accuracy, with full single-precision performance being fully suitable for whole-core transport calculations; the computational speedup for the C5G7 3D extension benchmark exceeded 40x, while that for the THFR 3D simplified model reached 5.6x, demonstrating a significant improvement in computational efficiency.

Keywords

High flux reactor, Neutron transport calculation, 2D/1D method, GPU

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