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位置灵敏 **3He** 管探测器读出电子学研究

摘要

中子散射作为研究物质微观结构与动态过程的重要手段，在凝聚态物理、化学、材料科学、高分子及生命科学等领域具有广泛的应用。小角中子散射（Small Angle Neutron Scattering, SANS）技术，因其对微纳米尺度结构的灵敏探测能力，成为相关领域不可或缺的研究工具。目前，基于清华大学微型脉冲强子源（Compact Pulsed Hadron Source, CPHS）正在建设新型 SANS 谱仪，其主探测器采用 3He 管阵列探测器以实现大面积中子探测。该探测器阵列由 96 根有效长度为 800 mm、直径为 8 mm 的位置灵敏型 3He 管组成，模块化设计共分为 6 个单元，每单元集成 16 根 3He 管及配套电子学。为避免空气对中子的杂散，探测器阵列整体置于真空腔体内，专设电子学腔放置读出电子学，并使用波纹管连接保持常压环境，有效避免高压放电。信号处理方面，采用电荷分配法和 CR-RC4 滤波器，结合 FPGA 实现实时数据采集与处理，最终获得中子事件的位置及波长信息。经 CPHS 实际束流测试，探测器模块表现出优良性能：位置分辨率优于 4.0 mm，坪斜度绝对值小于 1%/100V，探测效率达到 61.1%。

关键词

数字信号处理、中子探测器、3He 探测器、位置分辨率、读出电子学

Abstract

Neutron scattering is a crucial technique for investigating the microscopic structure and dynamic processes of materials, widely applied in condensed matter physics, chemistry, materials science, polymer science, and life sciences. Small Angle Neutron Scattering (SANS), as a key method, provides unparalleled sensitivity to structures at the nano- and submicron scale, making it indispensable in related fields. Based on the Compact Pulsed Hadron Source (CPHS) at Tsinghua University, a new SANS spectrometer is under construction, featuring a large-area 3He tube array detector for neutron detection. The detector array consists of 96 linear position-sensitive 3He tubes, each with an effective length of 800 mm and a diameter of 8 mm, modularized into six units, each integrating 16 tubes and readout electronics. To avoid neutron scattering by the air, the detector array is housed in a vacuum chamber; a dedicated electronics vessel connected via bellows to maintain atmospheric pressure, houses the readout circuits, effectively preventing high-voltage discharge. Signal readout is achieved using a charge division method and CR-RC4 filtering, with real-time data acquisition and processing implemented in FPGA to extract neutron event position and wavelength information. Beam tests at CPHS demonstrate excellent detector performance: position resolution better than 4.0 mm, plateau slope absolute value less than 1%/100V, and detection efficiency of 61.1%.

Keywords

3He detector, position resolution, SANS, readout electronics

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