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C3Po1F-08: Power requirements and energy recovery in Stirling and pulse tube cryocoolers for space missions

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Space cryocoolers permit cryogenic cooling of space-based astronomy instruments and a range of other sensors and detectors across electromagnetic wavelengths. This study investigates the energy requirements and performance of various cryocooler designs, with a focus on Stirling, pulse tube, and Stirling pulse tube cryocoolers (SPTCs). These systems are essential for missions requiring high reliability, minimal vibrations, and efficient cooling. The Stirling cryocooler utilizes a displacer to transfer heat efficiently, while the pulse tube cryocooler achieves low vibration by eliminating moving parts at the cold end. The SPTC integrates advantages from both systems, offering high efficiency and minimal thermal noise, making it particularly suited for next-generation space missions. Key aspects analyzed include power requirements, cooling efficiency, and energy recovery mechanisms. Innovations such as displacers for energy recovery and advanced phase shifters are highlighted, demonstrating their impact on improving system performance. Comparative evaluations reveal the operational trade-offs between different cryocooler types, emphasizing the importance of design choices for specific mission requirements. The study investigates in further detail the SLSTR cryocooling instrument on-board Sentinel-3 and pulse tube systems in the James Webb Space Telescope, and discusses the design considerations undergone to permit their long-term reliability and precision. Despite advancements, challenges remain in optimizing energy usage and further reducing thermal noise. This work consolidates knowledge on cryocooler technology, providing a foundation for future research and development. By addressing current limitations and exploring novel energy recovery methods, the study paves the way for more efficient and reliable cryogenic systems in space exploration.

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