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C1Or2B-02: Improving energy efficiency and cryocooling performance through independent speed control of cryocoolers and compressors

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Energy efficiency and reduced power consumption are critical for modern cryogenic systems. Gifford-McMahon (GM) cryocoolers provide an economical, cryogen-free solution across a broad range of temperatures, offering high energy efficiency, reliable long-term performance, and easy maintenance thanks to their simple mechanical design. Compact size and low vibration levels make them especially suitable for precision applications, ranging from analytical instrumentation to large-scale astronomy arrays.

This work showcases optimization of GM cryocooler operation by dynamically adjusting performance of the coldheads'and compressors. Precise cryogenic cooling is achieved, ensuring temperature stability over extended operation periods. Unlike traditional methods that rely on heating adjustments and often compromise efficiency, our approach matches heat lift to application demands while minimizing energy losses. Additionally, variable-speed control of the helium compressor further enhances energy efficiency by synchronizing its operation with the GM cryocooler, reducing excess cooling and the need for controlled heat dissipation.

We present a proof-of-concept performance analysis of an adjustable GM cryocooler system, demonstrating how tailored speed modulation enables optimized performance, reduces energy consumption, and lowers the operational costs of cryogenic systems. This strategy is particularly advantageous for long-term applications, offering a sustainable solution with reduced environmental impact.

High-speed coldhead operation is essential for handling high thermal loads or achieving rapid cooldowns. In this case study, Oxford Cryosystems Ltd (OCS) Coolstar 6/30 coldhead is operated at variable speeds. Increasing operational speed from 60 rpm to 90 rpm reduces the cooldown time by 34 % and provides cooldown rates up to 12.85 K/min. The OCS GMi controller dynamically optimizes coldhead speed to match system load, ensuring efficient performance. In addition, the OCS helium compressor maintains a constant differential pressure regardless of the gas demand from attached coldheads. When cooling demand is low, it results in substantial power savings. Conversely, during high cooling demand, such as when multiple coldheads are attached or the lowest temperatures are required, the compressor adjusts its speed to maintain system performance. The GMi controller fine-tunes the differential pressure to match system requirements, enabling significant energy optimization.

Performance data show operational potential of the coldhead across speeds ranging from 40 rpm to 90 rpm, as well as the dependency on differential pressure. By optimizing the differential pressure, compressor power consumption can be significantly reduced, which is especially critical for long-term operations. When operating al low cooling demand, it is possible to save up to 46 % of energy when compared to a standard fixed speed system, increase the coldhead lifetime by up to 50 %. Furthermore, at high cooling demand, it is possible to significantly reduce the cooldown times and still save up to 20 % of energy.
Moreover, we demonstrate benefits of running two different cold heads using one compressor, which allows for greater energy savings and offers operational flexibility.

This solution ensures cryogenic operations can be adjusted matching the cooling requirements, which is especially useful when heat load changed during the operation.

Keywords: Cryocoolers, Coldheads, Gifford-McMahon Cycle, Adjustable Speed Compressors, Energy Efficiency, Cryogenic Systems, Precision Applications

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