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C2Po3C-02: Machine Learning Methods for Cryocooler Performance Optimization and Failure Prediction

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Space cryocoolers are required to cool sensitive instruments such as infrared detectors and superconducting devices to cryogenic temperatures. Recent advancements have focused on optimizing the performance and reliability of Stirling pulse tube cryocoolers (SPTCs), a hybrid design combining high efficiency and low vibration. This study explores the integration of machine learning (ML) techniques to benefit a range of aspects pertaining to optimizing cryocooler performance and predict component failures, with a focus on flexure springs, which play a critical role in ensuring long-term operational stability.

The first approach utilizes a Back Propagation Neural Network (BPNN) model to predict the failure of flexure bearing springs based on operational parameters such as frequency, amplitude, cycles, and time. By incorporating techniques such as data augmentation and Bayesian optimization, the model enhances predictive accuracy and reduces reliance on traditional methods like finite element analysis (FEA) and individual experimental testing by drawing from an large experimental dataset. The second approach applies ML for optimizing key design and operational parameters of SPTCs, including frequency, pressure, and phase angles. This optimization improves overall performance metrics, such as cooling power and Carnot efficiency at low temperatures, demonstrating the ability of ML to navigate complex parameter spaces more effectively than conventional simulation-based approaches.

This study highlights the potential of machine learning to transform cryocooler design and operation. By reducing development time, lowering costs, and improving the accuracy of performance predictions, ML methods provide a robust framework for addressing challenges in cryogenic systems. Future research should aim to expand datasets, refine predictive models, and explore a wider range of failure scenarios to further enhance the integration of machine learning into cryogenic engineering. These advancements pave the way for the development of next-generation cryogenic systems with improved performance and reliability, supporting a wide array of scientific and industrial applications.

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