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ABSTRACT:

Hybrid Computational Analysis of a Miniature Distributed Stirling Cryocooler for Satellite Thermal Control System

C.H. Cheng and P.C. Huang

National Cheng Kung University, 70101, Tainan Taiwan

Satellite technology is composed of multiple subsystems, among which the thermal control system holds a critical position. Every mechanical, electronic, and optical component has its allowable operating temperature range; excessive heat or cold can reduce performance, shorten lifespan, or even cause failure. Therefore, the primary purpose of the thermal control system is to ensure that the satellite operates within a safe temperature range under all mission modes. Satellite thermal control systems are divided into passive and active types. The Stirling cryocooler [1] is a widely used active cooling system for optical sensors, offering advantages such as high efficiency, compact size, low vibration frequency, and good reliability. The objective of this study is to design a miniature distributed Stirling cryocooler and to propose a hybrid analysis method that combines thermal modeling with three-dimensional computational fluid dynamics (CFD) modeling. This study employs a hybrid computational method that integrates computational fluid dynamics (CFD) with thermodynamic theoretical models, primarily through data exchange between the two models, which greatly reduces the numerical simulation time of the Stirling cryocooler [2]. In this approach, the CFD model receives information on heat and fluid conditions in all chambers from the thermodynamic model at the final stable periodic state, using it as the initial guess for CFD calculations. After performing a limited number of cycles, the CFD model then provides coefficients required by the thermodynamic model. The thermodynamic model is subsequently used to rapidly advance the simulation to the final stable periodic state. The predicted stable state is again introduced into the CFD model to update its initial guess. Typically, only a limited number of data exchanges and iterative calculations are needed to achieve the stable solution. This method can significantly reduce total computation time while improving the accuracy of the CFD model.

[1] J. S. Huang and C. H. Cheng, Thermal Science and Engineering Progress, 101996, 2023.

[2] C. H. Cheng, D. T. Phung, Energy Science & Engineering, Vol. 9(11), pp.2177–2190, 2021.