CFD INSIGHTS INTO THE EFFECT OF TAPERING ON OSCILLATING FLOW IN PULSE TUBES AND ITS IMPLICATIONS FOR CRYOCOOLER DESIGN

Kedam Naresh, Dmitry A. Uglanov, E. M. Umana, Hamza Adenane
Samara University, Samara, Naresh.kedam@gmail.com

Keywords: CFD, cryocooler, heat transfer, oscillating flow, pulse tube.

Pulse Tube Cryocoolers (PTCs) have emerged as a significant technology in the field of cryogenics, underpinning a range of applications from space exploration to medical imaging. PTCs operate by converting thermal energy into acoustic power, providing efficient, low-vibration cooling. One promising avenue of exploration lies in the geometric modification of the pulse tube, a critical component of the PTC [1] that dictates the system's heat transfer efficiency. In this study, we utilize CFD to investigate the effect of pulse tube tapering on the performance of PTCs.

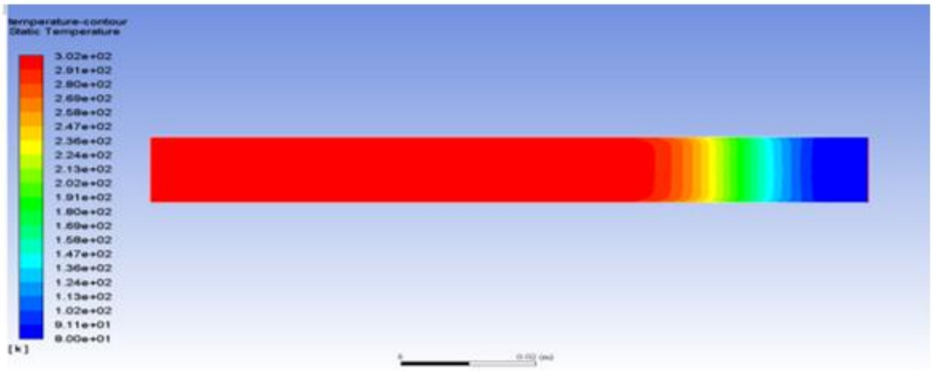

Fig. 1 – Static temperature contour of conventional straight pulse tube model

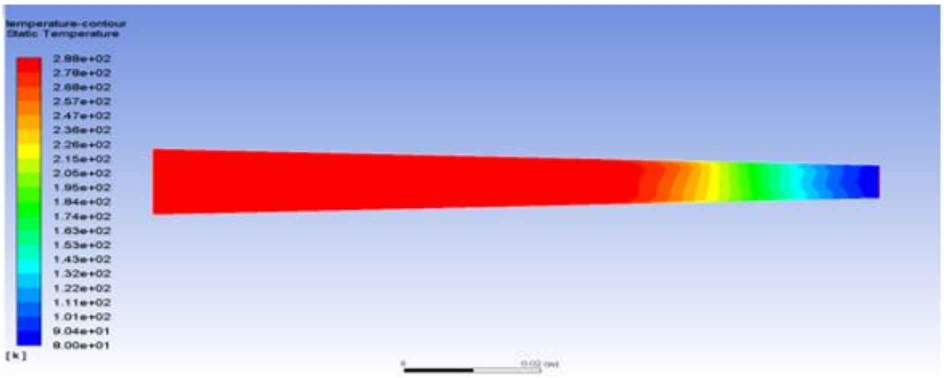

Fig. 2 – Static temperature contour of pulse tube tapered at cold end

Tapering, or varying the tube's diameter, could potentially influence the heat transfer efficiency and, thus, the overall cooling performance of PTCs. To date, there is a scarcity of quantitative research examining this impact, particularly within the context of inline and coaxial PTC configurations. Our objective is to elucidate the implications of tube tapering on the oscillating flow within pulse tubes and how these flow dynamics impact the cooling efficiency in both inline and coaxial PTC designs. Through this exploration, we aim to provide a foundation for future design optimizations that can enhance the performance of PTCs across their various applications. To do so, we designed three models representing pulse tubes with various tapering approaches. The first model, referred to as Model 1 (Fig.1), is a conventional straight pulse tube without any tapering. This design, featuring consistent flow parameters throughout the tube, is the typical configuration used in PTCs and served as a baseline in our analysis. The second model, Model 2 (Fig.2), introduces tapering at the cold end of the pulse tube. We hypothesized that this tapering might induce flow acceleration, potentially improving convective heat transfer, and leading to a greater temperature drop at the cold end of the tube.

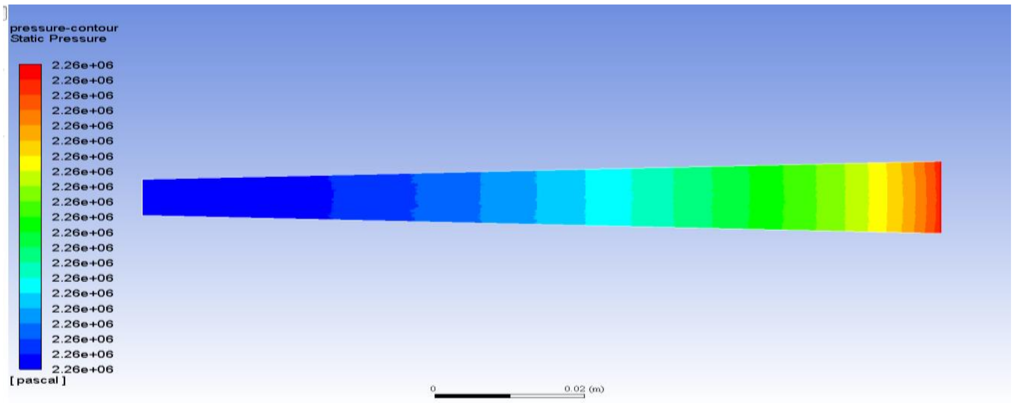

Fig. 3 – Static pressure contour of pulse tube tapered at hot end

Model 3, as opposed to the others, tapers the pulse tube at the hot end, a divergence hypothesized to foster efficient energy transfer but potentially causing flow instabilities and pressure fluctuations. We analyzed these models in both inline and coaxial Pulse Tube Cooler (PTC) configurations, the former being linear and the latter more compact with a surrounding regenerator. Computational Fluid Dynamics (CFD) analyses were conducted using standard operating conditions, considering key variables like mass flow rate and oscillating flow frequency. We aimed to evaluate heat transfer rate, cooling efficiency, and the presence of flow issues. Our objective was to understand how tube tapering affects PTC efficiency and performance, thereby creating a data-driven foundation for future PTC design optimization.

In this study, we performed a Computational Fluid Dynamics (CFD) analysis on three tube models: straight (Model 1), cold end tapered (Model 2), and hot end tapered (Model 3). Model 1's consistent flow parameters validated its stability but hinted at heat transfer optimization limitations. Model 2 showed improved heat transfer and cooling efficiency due to flow acceleration at the tapered cold end, suggesting potential benefits for pulse tube cryocoolers. In contrast, Model 3's hot end tapering caused flow instabilities and pressure fluctuations despite efficient energy transfer, indicating possible reliability issues.These findings underscore the role of geometric modifications in optimizing pulse tube cryocoolers' performance.

References

1. Yang L.W.: Experimental research of high frequency tapered pulse tube cooler, Cryogenics 49 (Compendex) (2009). PP. 738-741.

2. Dion S. A., Bakhtier F.: Numerical simulations of transport processes in a pulse tube cryocooler: Effects of taper angle, International Journal of Heat and Mass Transfer, Volume 54, Issues 21-22, 2011, PP. 4611-4620, ISSN 0017-9310.

Information about the authors

Kedam Naresh: PhD Scholar, Assistant Lecturer, Research interests are heat transfer, cryocoolers.

Dmitry A. Uglanov: Associate Professor, Research interests are heat transfer, cryocoolers, cryogenics.

E. M. Umana: Engineer, Research interests are heat transfer, cryocoolers.

Hamza Adenane: PhD student. Research interests: design of an unmanned aerial vehicle.