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THE EFFECTS OF TAPERED GEOMETRY ON THE COOLING PERFORMANCE OF A PULSE TUBE CRYOCOOLER

Umana E. M.[1], Yang X.[1], Uglanov D. A.[2], Kedam N.[2]
[1]Beijing Institute of Technology, Beijing, China, umana.emichael@gmail.com
[2]Samara University, Samara, Russia

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The effects of tapered geometry on heat transfer characteristics in a Pulse Tube Cryocooler are investigated in this scientific study. The research presents the analysis of two tapered pulse tube cryocooler designs: with tapering and divergence at different ends of the pulse tube. The concept of tapered pulse tubes, where the tube diameter gradually changes along its length, has emerged as a promising design approach to enhance the performance of pulse tube cryocoolers [1]. The results proved that incorporating tapering and divergence in the pulse tube significantly influenced the cooling performance of the cryocoolers.

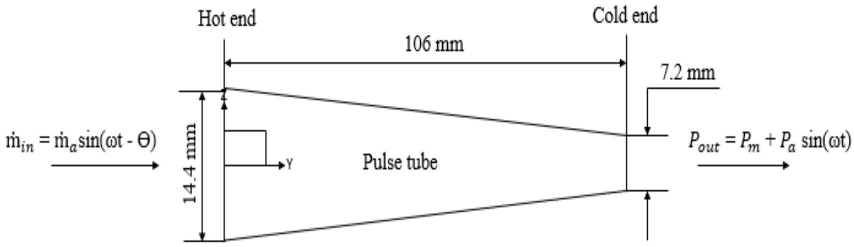

Fig. 1. Schematic of CFD model of Pulse Tube tapered at the Cold End (Model 1)

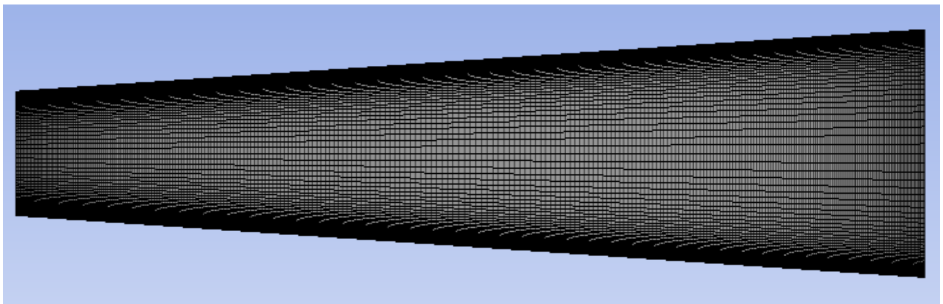

Fig. 2. Mesh generation of Pulse Tube tapered at the Hot End (Model 2)

The tapering of the pulse tube means the cross-sectional area of the tube varies along its length. This has significant implications for heat transfer in terms of flow velocity variation, pressure drop, and thermal diffusion. As the tube narrows, the gas velocity increases, which can enhance convective heat transfer but also leads to increased viscous losses. The changing cross-sectional area leads to pressure variations that influence the overall cooling performance. In tapered tubes, thermal diffusion can be more complex due to the varying geometry, which can affect the phase relationship between pressure and temperature oscillations, a critical factor in achieving efficient heat transfer [2]. We aim to explore the impact of tapering and divergence on flow dynamics and heat transfer characteristics in pulse tubes using Computational Fluid Dynamics (CFD) for the design and optimization of pulse tube cryocoolers. Hence, two tapered models (Model 1 and Model 2) with tapering at either the cold end or the hot end of the pulse tube was designed. Fig. 1 illustrates the schematic of a pulse tube with tapering at the cold end. The geometry of the pulse tube models is accurately represented using appropriate meshing techniques as shown in Fig. 2. The mesh should be refined near the boundaries and areas of interest to capture the flow and heat transfer phenomena effectively [2].

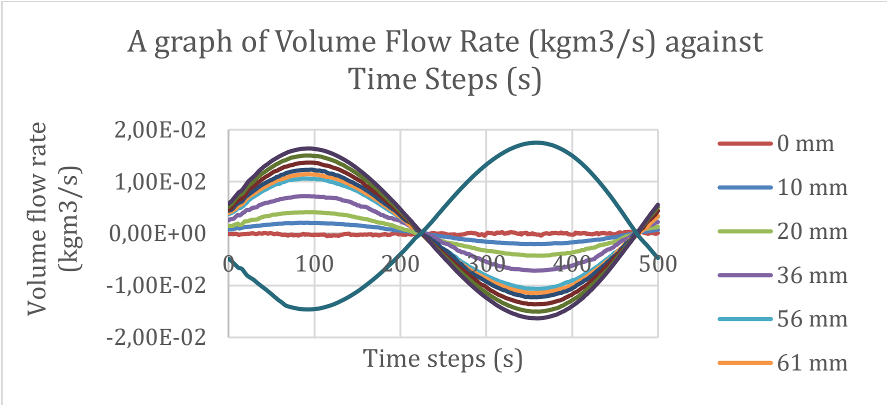

Fig. 3. A graph of Volume Flow Rate (kgm^3/s) against Time Steps (s) at different locations along the pulse tube length (Model 1)

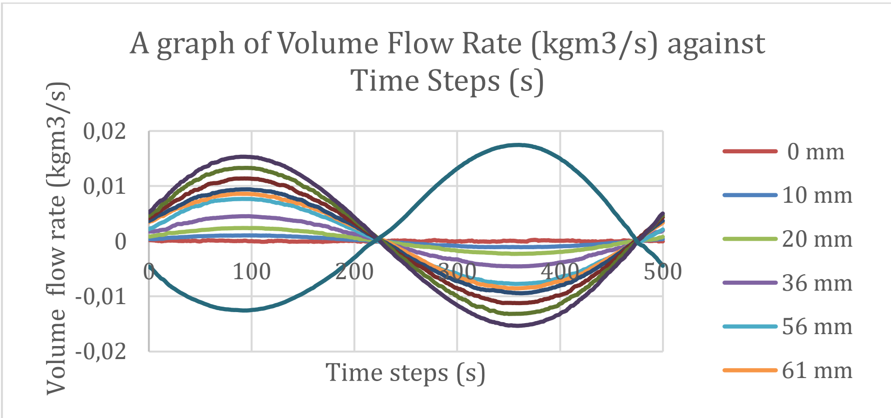

Fig. 4. A graph of Volume Flow Rate (kgm^3/s) against Time Steps (s) at different locations along the pulse tube length (Model 2)

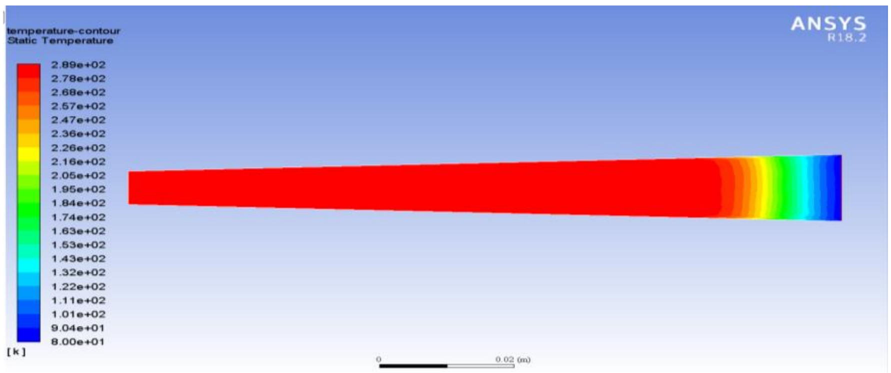

Fig. 5. Static temperature contour of Pulse Tube tapered at the Hot End (Model 2)

The comparison between the two tapered pulse tube models reveals intriguing insights into the performance enhancements reached through the initiation of tapering and divergence in the pulse tubes. To evaluate the reliability and effectiveness of the pulse tube designs, various flow parameters such as enthalpy, internal energy, static pressure, static temperature, velocity magnitude, mass flow rate, and volume flow rate were analysed. The variations in volume flow rate offered insights into the volumetric flow characteristics along the pulse tubes as shown in Fig. 3 and 4 respectively. Both models showed patterns resembling sinusoidal or cosine waves in the volume flow rate. Model 1 exhibited fluctuations with distinct peaks and troughs, while Model 2 showed similar patterns but with larger amplitudes.

These results suggest that tapering and divergence influence the volumetric flow behavior in the pulse tubes, leading to enhanced flow dynamics and performance when compared to the conventional straight pulse tube design which showed a relatively constant volume flow rate along the tube length. Fig. 5 illustrates that tapered pulse tube designs demonstrate improved energy transfer, more efficient internal energy distribution, altered pressure oscillations, temperature distribution variations, and modified flow dynamics in contrast to the conventional straight pulse tube design. The results show that incorporating tapering and divergence in the pulse tubes modifies the flow and heat transfer characteristics, leading to enhanced performance.

This research focuses on the analysis of flow parameters in two distinct pulse tube cryocooler models: Model 1, where the pulse tube is tapered at the cold end, and Model 2, with tapering at the hot end, in comparison to the conventional straight pulse tube design. The analysis examined several flow parameters, such as enthalpy, internal energy, static pressure, static temperature, velocity magnitude, mass flow rate, and volume flow rate. In Model 1, tapering improved heat transfer, leading to greater cooling efficiency. In Model 2, divergence facilitated effective energy transfer but also caused flow instabilities and pressure fluctuations.

The results highlight the significance of accounting for tapering and divergence effects in the design and optimization of pulse tube cryocoolers. It explains how tapering and divergence affect flow dynamics and heat transfer characteristics, providing crucial insights for future design enhancements.

References

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Information about the authors

Umana Edidiong Michael: PhD Scholar, Research Assistant, Research interests are Computational Fluid Dynamics, Cryocoolers, Multiphase Flow, Free Surface Flow, Heat & Mass Transfer.

Yang Xiufeng: Associate Professor, Research interests are Computational Fluid Dynamics, Fluid Structure Interaction, Multiphase Flow, Free Surface Flow, Heat & Mass Transfer

Dmitry A. Uglanov: Professor, Research interests are Heat Transfer, Cryocoolers, Cryogenics.

Kedam Naresh: Assistant Lecturer, Research interests are Heat Transfer, Cryocoolers.