# Exploring the Efficacy of a Novel Inertance Tube to Improve Pulse-Tube Cryocooler Design

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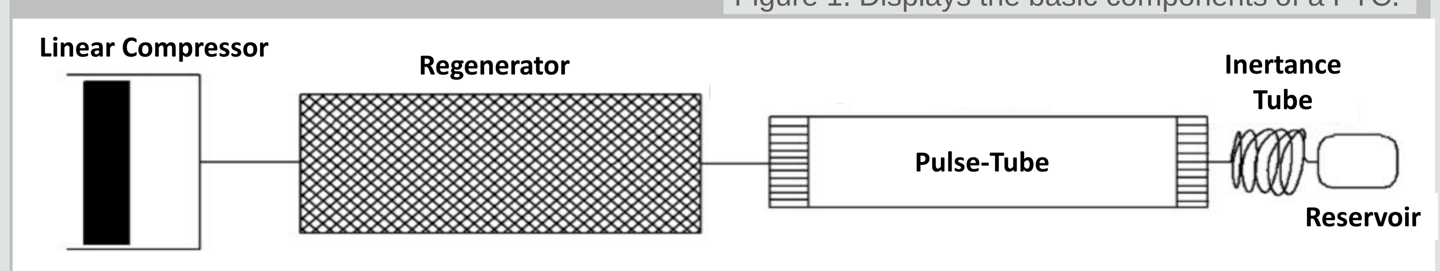
## Objective

To further investigate the feasibility of an inertance tube that can shift the phase angle between the pressure and mass flow waves, while a pulse-tube cryocooler (PTC) is operating. By shifting to an optimal phase angle, PTC cooling performance can be improved.

## Where/why are PTC's used?

- Maintain instruments at operating temperature for:
  - Space Telescopes
  - MRI Machines [1]
  - Helium Recovery Systems [1]
- High reliability and long lifetimes
  - Few moving parts [1]
  - Low vibrations generated

Figure 1. Displays the basic components of a PTC.




## Inertance Tube Background

- Shifts phase angle between mass and pressure waves
  - Can be shifted to an angle that optimizes cooling performance [1]
  - Phase angle shift dependent on length and diameter of tube
- Finding best inertance tube is time-intensive and costly
  - Must be found experimentally
  - Buying multiple inertance tubes and working gas is expensive
  - PTC's take hours to reach steady state → long time to test one tube

## The Adjustable Inertance Tube

- First Concentric Screw Configuration

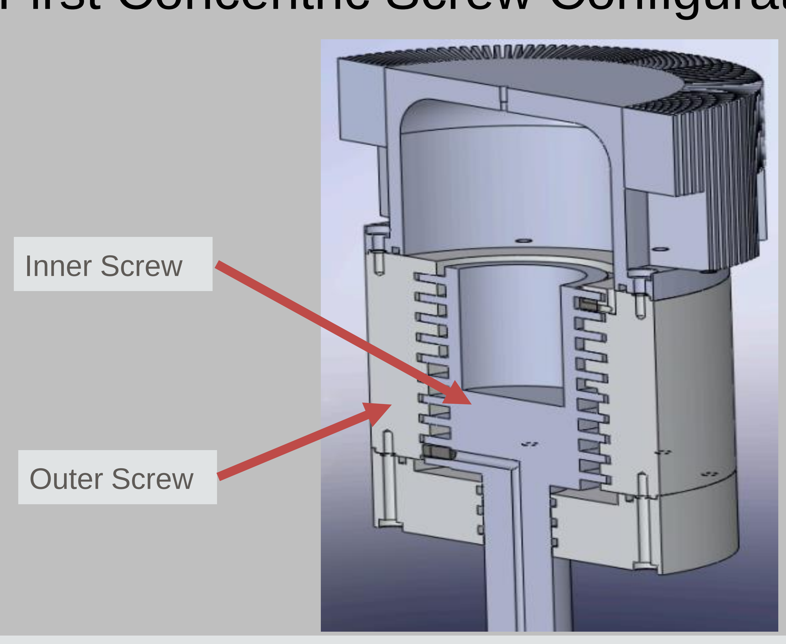
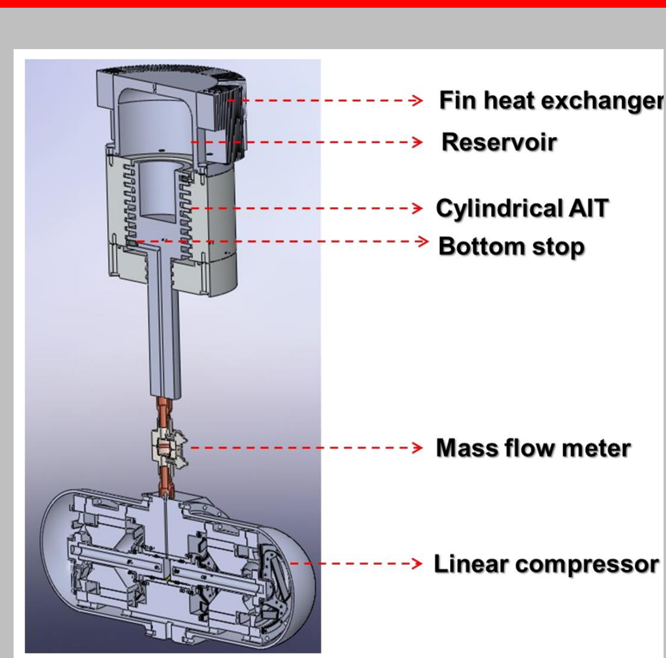



Figure 2. The Concentric Screw Adjustable Inertance Tube shifts the phase angle by changing the length and diameter of a helical flow path formed by the roots of the inner screw and the teeth of the outer screw. By rotating the outer screw around the inner screw, the length and diameter of the path changes. [2]

## Methods




**Experimental Parameters**

- Charged system with 300psi of $N_2$
- Tested 40Hz - 60Hz frequencies
- Recorded data every quarter turn
  - 4.5 turns in total

Figure 3. The experimental setup and equipment used to obtain phase angle shift data

- Two pressure transducers placed on mass flow meter
  - Pressure wave found from mass flow meter inlet transducer
  - Mass flow wave found from pressure difference across flow meter
- 42 wave cycles averaged for each wave to diminish noise effects
- Found phase angle from fitting a sine wave to averaged cycle in EES
  - Subtracted mass flow phase from pressure phase

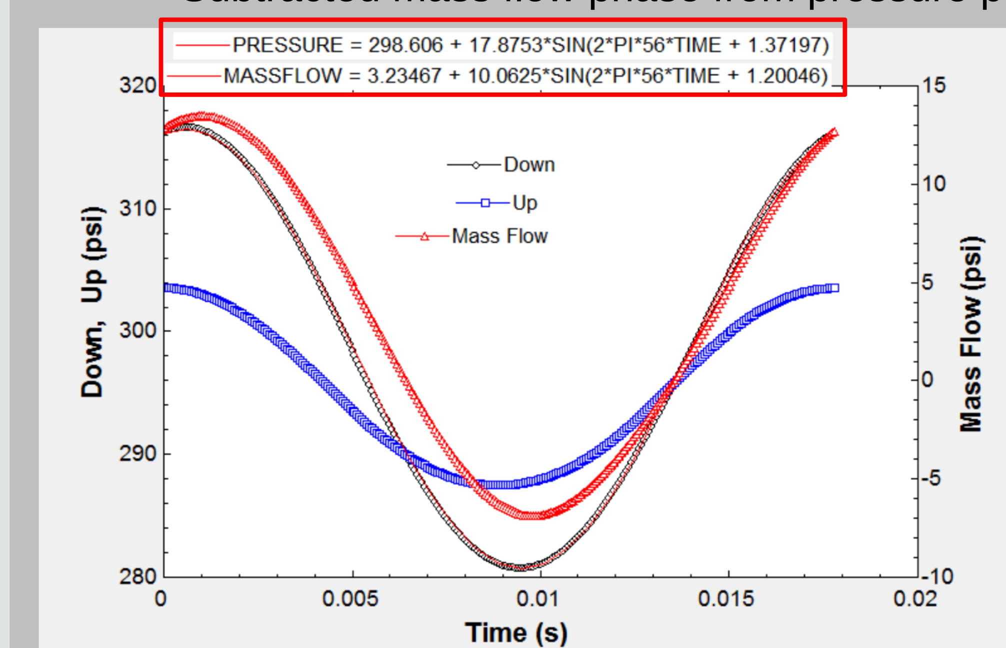



Figure 4. The data from the two averaged cycles were loaded into EES to apply a sinusoidal curve-fit. Once each wave was fit with a curve, the mass flow phase was subtracted from the pressure phase to obtain the phase angle.

## Initial Configuration Results

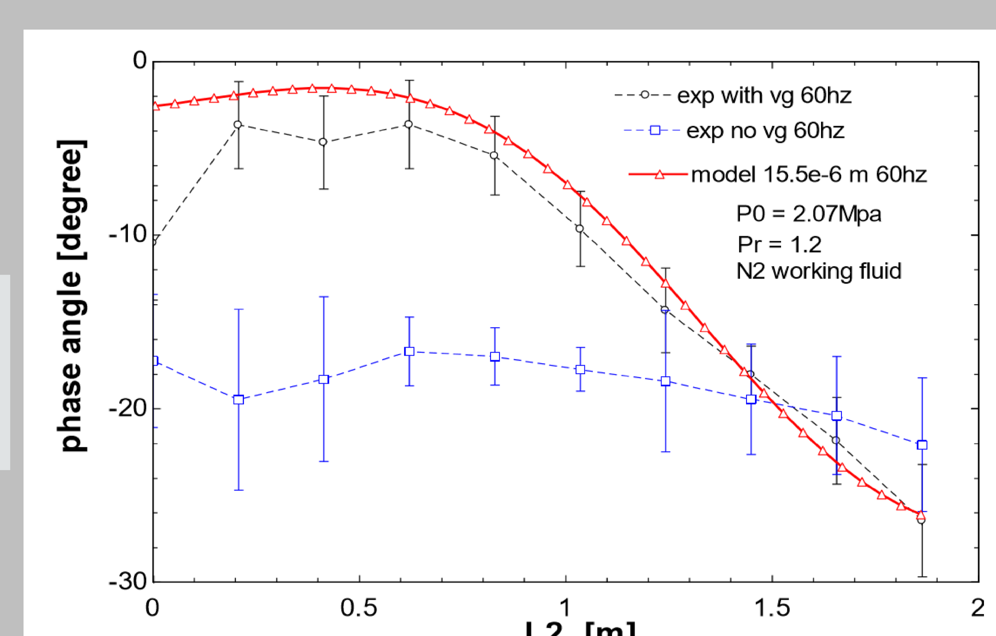



Figure 5. The largest phase angle shift was 22° at 60Hz. [2]

- First trial had a phase angle shift of only 6°
- Found that gas was leaking to, and from, the outer helical flow path [3]
  - Outer path formed by teeth of inner screw and roots of outer screw
  - Vacuum grease applied to create a better seal between paths [3]
- Achieved max phase angle shift of 22° at 60Hz with vacuum grease

## Modification to Decrease Leakage

- Placing outer flow path in parallel with inner flow path predicted a much larger phase angle shift [4]

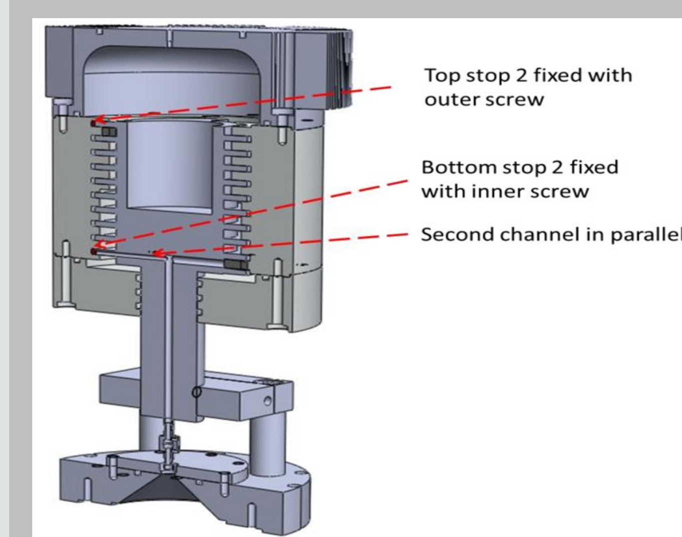



Figure 6. To decrease the leakage between flow paths, a channel was machined to connect the outer helical flow path in parallel with the inner one.

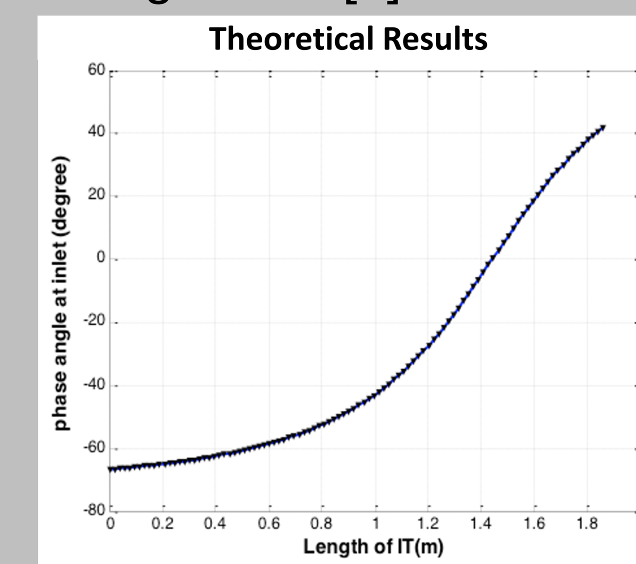



Figure 7. The predicted phase angle shift with the parallel flow path configuration was from -65° to +40°, for an overall phase angle shift of 105°.

## Parallel Path Configuration Results

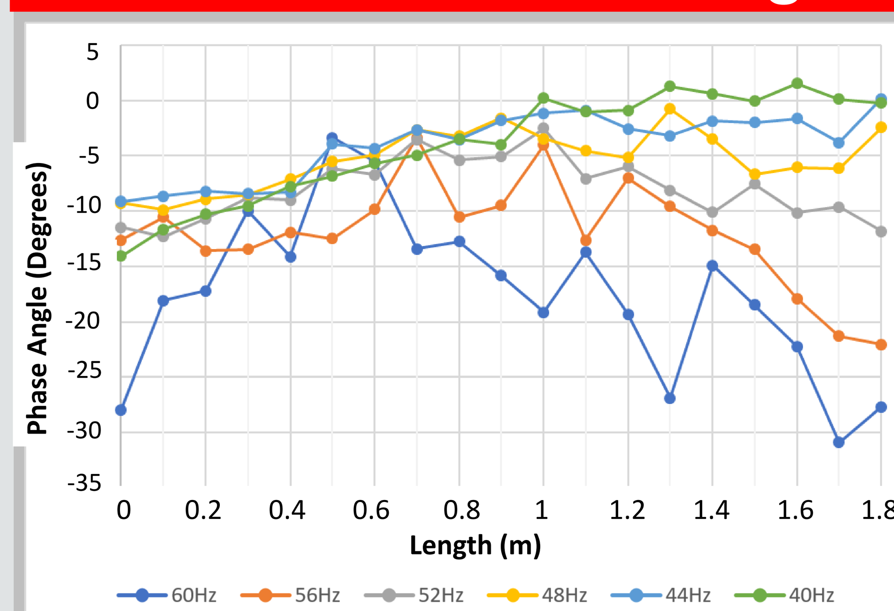


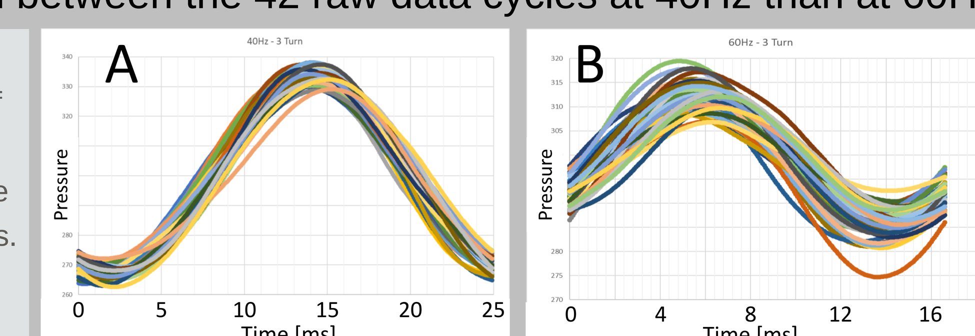

Table 1. Summary of largest phase angle shifts for each frequency.

| Frequency (Hz) | Max Phase Shift (Deg) |
|---|---|
| 40 | 16 |
| 44 | 9 |
| 48 | 9 |
| 52 | 9 |
| 56 | 19 |
| 60 | 28 |

Figure 8. The largest phase angle shift was 28° at 60Hz, which was much smaller than the 105° predicted shift.

- Largest phase angle shift was 28° at 60Hz
- Lower frequencies had smoother curves compared to higher frequencies
  - Less variation between the 42 raw data cycles at 40Hz than at 60Hz

Figures 9. A comparison between the 42 raw cycles of a 40Hz (A), and a 60Hz (B), trial was done to compare the variation between their cycles. The 60Hz trial had much more variation in the cycles.




## Conclusions

- The largest **experimental phase angle shift was only 28°**, whereas the **predicted phase angle shift was 105°.**
- **Parallel flow path only increased phase angle by 6°.**
  - Try using a different working gas, like helium, and compare results
- As **frequency increased**, **more variation in the raw pressure cycles** was seen.
  - Increasing current into the compressor could reduce noise effects

## References

[1] Pfotenhauer, J. M., & Zhi, X. Q. (2015). Pulse Tube Cryocoolers.
[2] Zhou, W. J. (2016). Adjustable Inertance Tubes for Pulse Tube Cryocoolers.
[3] Zhou, W. J., Pfotenhauer, J. M., Nellis, G. F., & Liu, S. Y. (n.d.). Performance of an adjustable, threaded inertance tube.
[4] Zhou, W. J., Pfotenhauer, J. M., & Nellis, G. F. (n.d.). Recent Progress with an Adjustable Inertance Tube.