An inter-phasing Stirling-type pulse tube cryocooler without reservoirs

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Background

Stirling pulse tube cryocooler is an important regenerative cryocooler which promises high efficiency and high reliability. It is widely used in the fields of space, military, telecommunications, et al. To achieve high efficiency, an inertance tube with a reservoir is needed to obtain ideal phase relationship in it. The volume of the reservoir is more than ten times greater than the pulse tube, which greatly reduces the specific power of the cryocooler. This is undesirable for space and military applications that require a small size and weight.

Objectives

❖ Explore configurations of Stirling-type pulse tube cryocoolers without reservoirs to improve the specific power.

❖ Theoretical and Experimental verification for the feasibility of a inter-phasing Stirling-type pulse tube cryocooler without reservoirs .

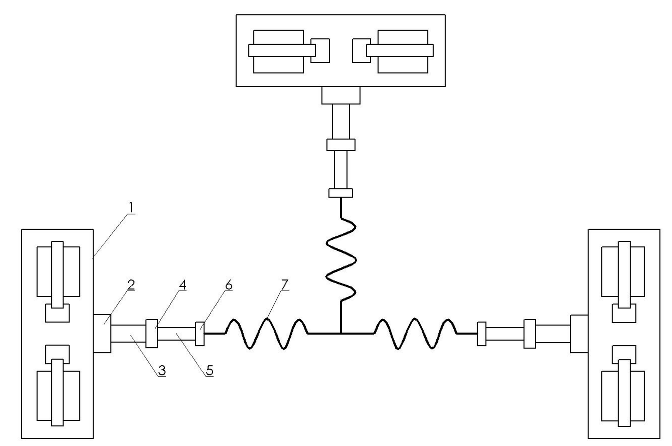
Conclusion

❖ An inter-phasing configuration conjoining n cold fingers was introduced to cancel the reservoirs in Stirling-type pulse tube cryocoolers.

❖ Theoretical analysis and experimental results show that this inter-phasing pulse tube cryocooler can achieve the same cooling performance as that of the traditional.

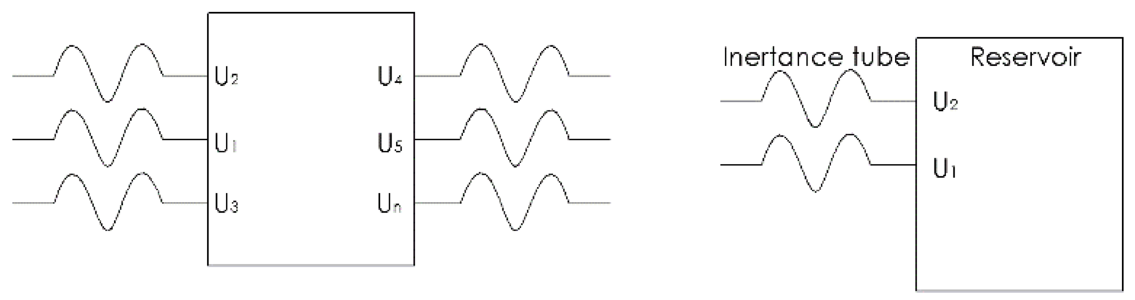
❖ It would be helpful to improve the specific power of the pulse tube cryocooler especially where the cooling load is beyond the capacity of one cold finger as it contains no reservoirs.

Possible Configuration



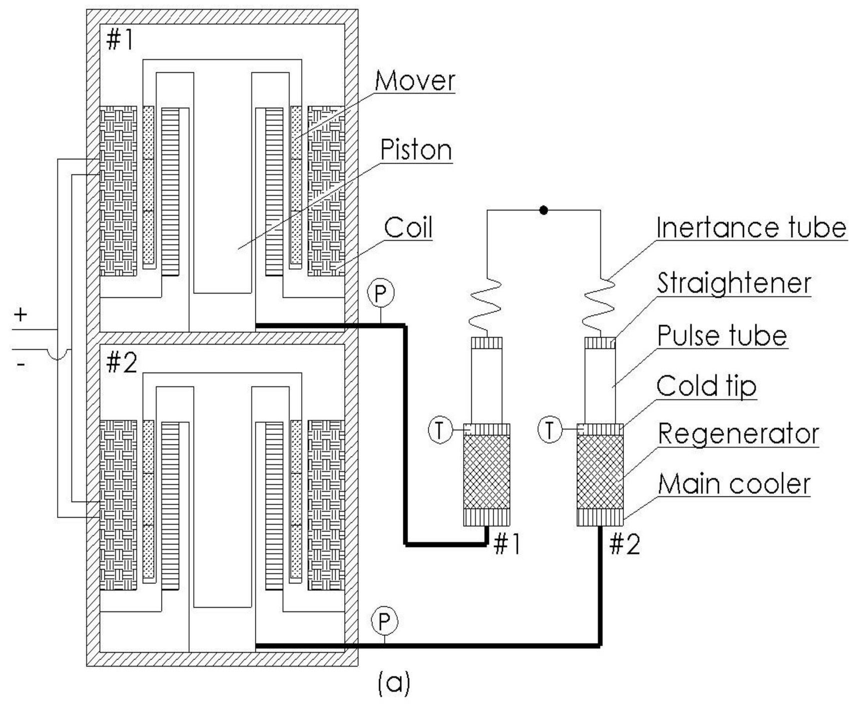
Analysis

Volume Flow and Pressure in a Reservoir



For a reservoir connected with n inertance tube, the pressure amplitude in it is zero as long as $U_1+U_2+U_3+\ldots+U_n=0$.
The simplest case is only two inertance tube connected with the reservoir. The flow amplitudes in them are equal and their phase difference is 180°. The total mass flow into the reservoir and hence the pressure amplitude are zero, regardless of the reservoir volume. Thus, the reservoir can be removed.

Configuration of Inter-phasing PTC



The inertance tubes of the cold fingers are connected together.

The two compressors are placed in series with the same orientation.

The currents in the two compressors are in antiphase so that the movement of the pistons are in antiphase and vibrations cancel.

Numerical Results

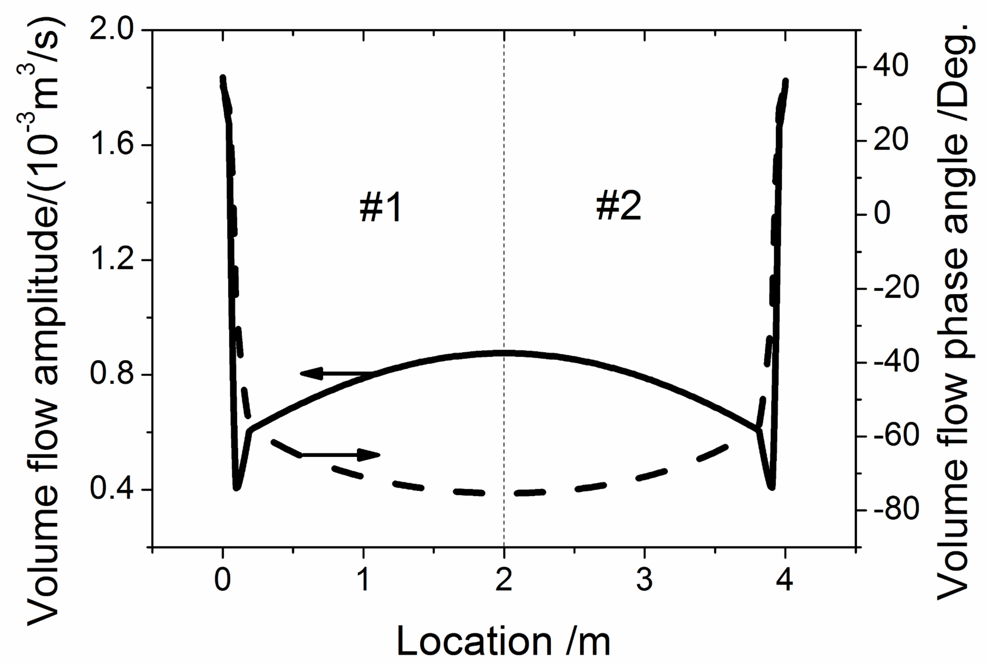
Dimensions

Parameters	Value
Working frequency	75 Hz
Charging pressure	3.5 MPa
Cooling temperature	77 K
Diameter and length of regenerator	⌀30 mm, L45 mm
Diameter and length of pulse tube	⌀16 mm, L80 mm
Inertance tube	⌀4 mm, L1.8 m
Volume of the reservoir	0.001 m^3

Volume Flow Distribution

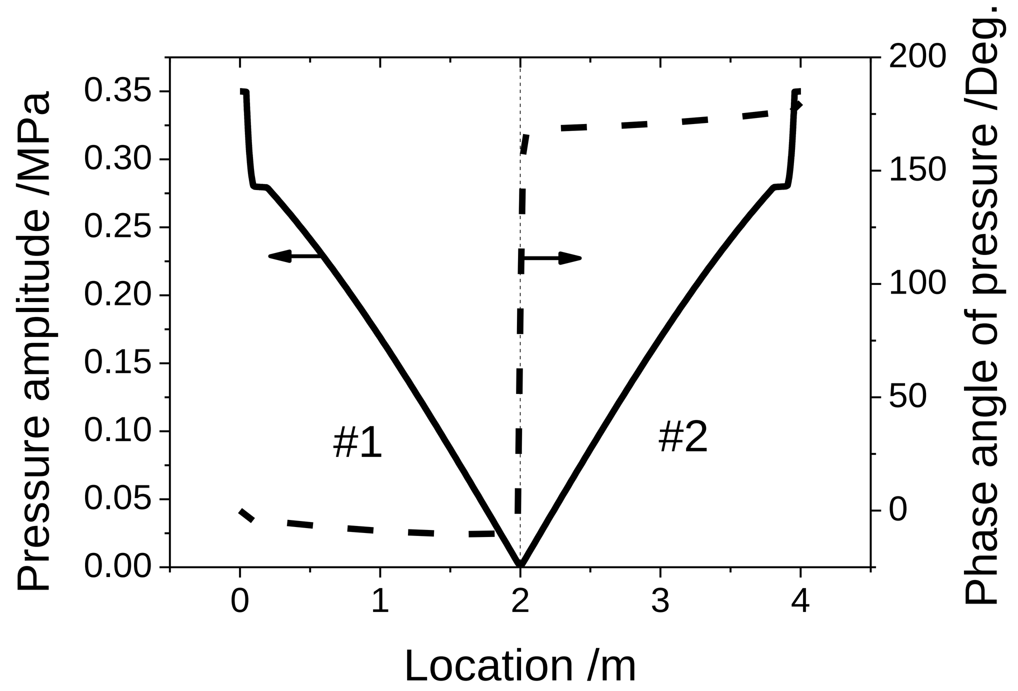
Considering a pathway starts from the main cooler inlet of cold finger #1 and ends at the main cooler outlet of cold finger #2, the volume flows in the two main coolers are set the same and in phase.

Because the two cold fingers are at opposite ends of the pathway, the distribution is perfectly symmetrical.



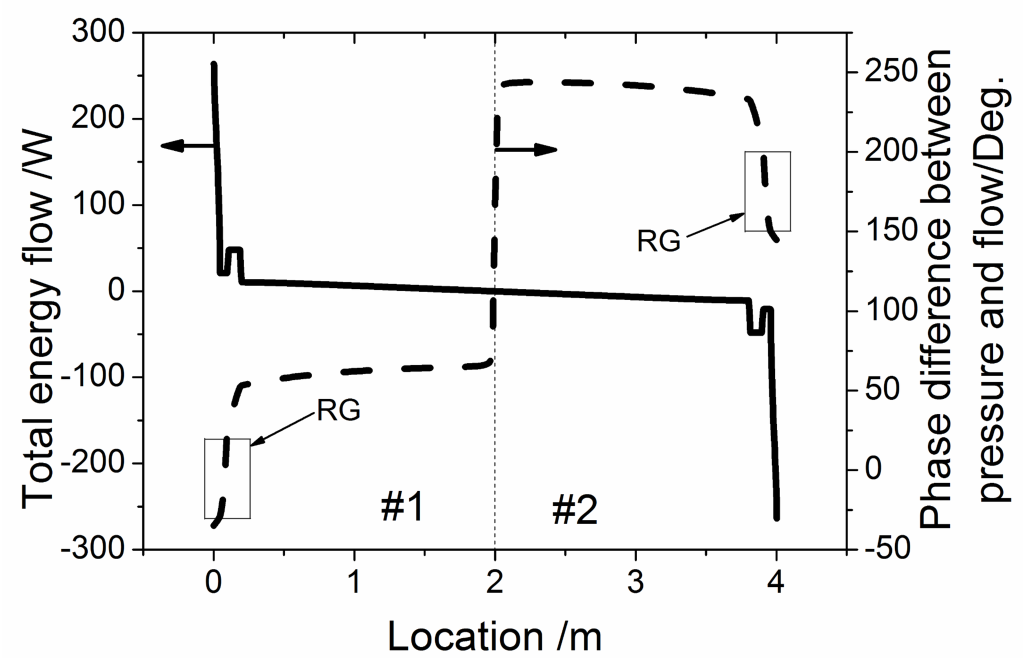
Numerical Results

Pressure Distribution



The pressure phase difference in the two cold fingers is approximately 180°. At the inertance tube junction, the pressure amplitude is zero as expected.

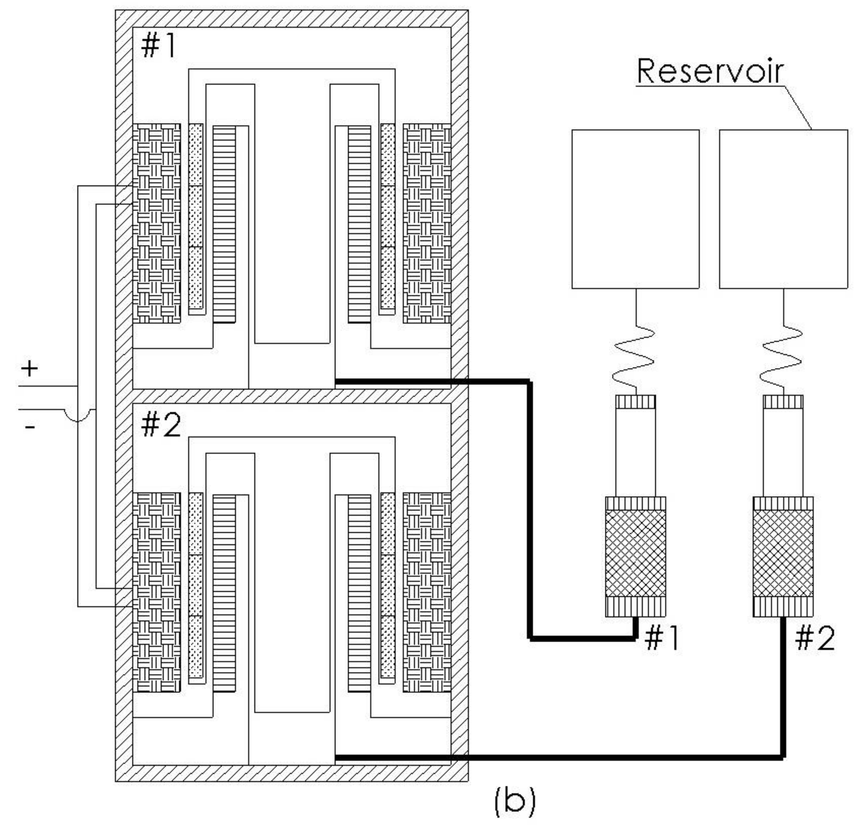
Energy and Phase Distribution



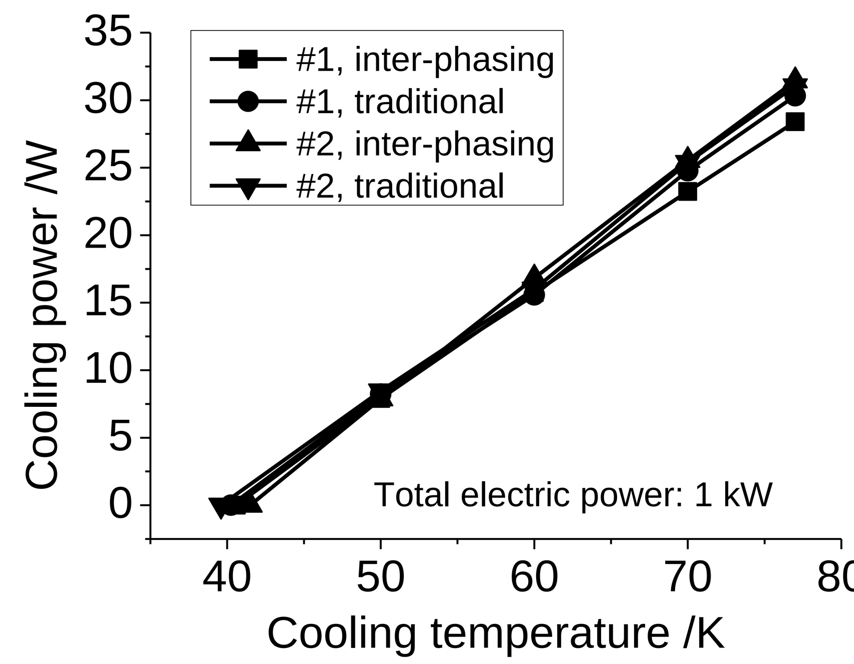
The pressure and flow are in phase or antiphase in the middle of the regenerators (RG), which implies an ideal phase relationship. The total energy flow distribution indicates that the acoustic power consumed by each compressor is 263.7 W and the cooling power at 77 K is 27 W.

Experimental Results

Traditional Configuration



Cooling power VS Temperature



In the iner-phasing configuration, the lowest cooling temperatures of cold fingers #1 and #2 are 40.6 K and 41.5 K, respectively, and the cooling powers at 77 K are 28.4 W and 31.4 W. In the traditional configuration, the lowest temperatures are 40.3 K and 39.6 K, and the cooling powers at 77 K are 30.3 W and 31.1 W.

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