Transient analysis of single stage GM type double inlet pulse tube cryocooler

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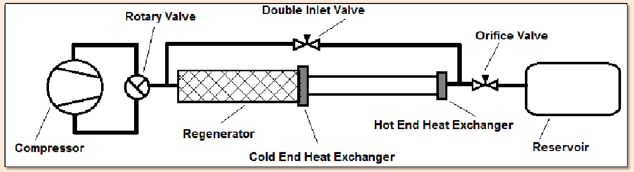


Various analysis and Design models

- Enthalpy Flow analysis
- Phasor Analysis
- Isothermal Model
- Numerical Model

Transient Numerical Model

- Estimates the cool down behavior
- Uses the Conservation laws
- Higher accuracy in solution

Assumptions in Numerical Model

- 1D flow of compressible helium gas
- No axial conduction in solids
- Reservoir pressure is considered as constant
- Pressure drop in pulse tube is neglected

Continuity Equation

$$\frac{\partial m}{\partial t} = \dot{m}_{in} - \dot{m}_{out}$$

Energy Equation for Solid

$$m_w \frac{\partial (C_w T_w)}{\partial t} = \alpha A (T - T_w)$$

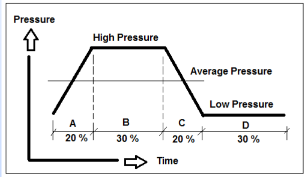
Energy Equation for Gas

$$\frac{\partial (m C_p T)}{\partial t} + \frac{\partial (\dot{m} C_p T)}{\partial x} + \alpha A (T - T_w) - V \frac{dP}{dt} = 0$$

Momentum Equation

$$\frac{\partial P}{\partial x} = -f \frac{1}{2 D_h} \rho u^2$$

- Finite Volume Method (Discretization)
- Gauss Siedel Iterative Method
- Pressure and Temperatures (Node of a cell)
- Mass flow rate /Velocity (Face of a cell)
- Second Order Upwind Scheme (Advection terms)



$$P = P_L + \frac{t}{\beta \tau}(P_H - P_L) \quad \text{(A)}$$

$$P = P_H \quad \text{(B)}$$

$$P = P_H - \frac{(t - \frac{\tau}{2})}{\beta \tau}(P_H - P_L) \quad \text{(C)}$$

$$P = P_L \quad \text{(D)}$$

Orifice mass flow rate

$P_N > P_{avg}$

$$\dot{m}_o = C_d A_o \left[\frac{2 P_N (P_N - P_{avg})}{R T_N} \right]^{\frac{1}{2}}$$

$P_N < P_{avg}$

$$\dot{m}_o = -C_d A_o \left[\frac{2 P_{avg} (P_{Pavg} - P_N)}{R T_{res}} \right]^{\frac{1}{2}}$$

The same way, Double Inlet mass flow rate can be calculated

The algebraic difference between orifice and double inlet mass flow rate serves as mass flow rate boundary condition at Right end.

Left end, Temperature boundary

$T_b = T_{in}$ for $\dot{m}_{left} \geq 0$ (Left to Right flow)

$T_b = T_{gas}$ for $\dot{m}_{left} < 0$ (Right to Left flow)

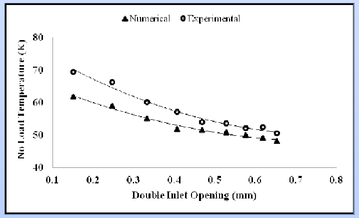
Right end, Temperature boundary

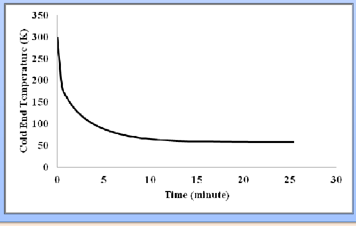
$T_b = T_{gas}$ for $\dot{m}_{right} \geq 0$ (Left to Right flow)

$T_b = T_r$ for $\dot{m}_{right} < 0$ (Left to Right flow)

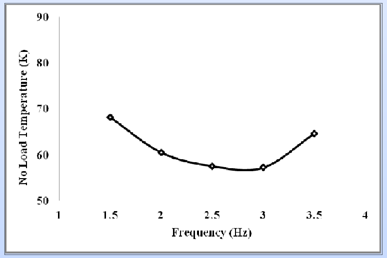
Input Data

Sr. No	Particulars	Value
1	Regenerator Length	210 mm
2	Regenerator ID	16.5 mm
3	Matrix material	# 200 SS wire mesh
4	Pulse Tube Length	230 mm
5	Pulse Tube ID	15 mm
4	High pressure	20 bar
5	Low pressure	8 bar

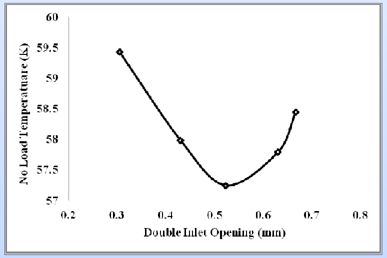




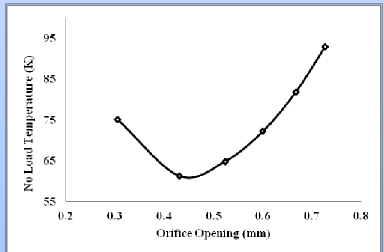
Effect of Operating frequency on No Load Temperature



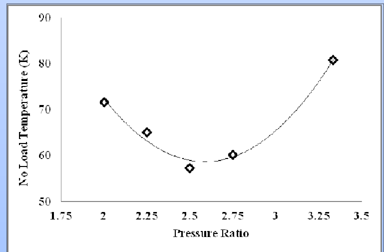
Effect of Double Inlet Opening on No Load Temperature



Effect of Orifice Opening on No Load Temperature



Effect Pressure Ratio on No Load Temperature



Effect of Pulse Tube geometry

Sr. No	Length (mm)	Inner Diameter (mm)	Cold end Temperature (K)
1	230	15	57.25
2	200	15	59.24
3	250	15	56.28
4	230	13	63.20
5	230	16	64.18

Effect of Regenerator geometry

Sr. No	Length (mm)	Inner Diameter (mm)	No load Temperature (K)
1	210	16.5	57.25
2	190	16.5	64.70
3	230	16.5	59.76
4	210	15	66.60
5	210	18	63.49

Effect of Pressure Ratio

Sr. No	Pressure Ratio	Refrigeration Temperature at 1W (K)
1	2	75.63
2	2.25	68.90
3	2.5	61.07

Conclusion:

A transient numerical analysis for single stage GM type double inlet pulse tube cryocooler is presented here. The model can be used as design tool to investigate effect of geometrical parameters as well as capable of doing theoretical investigations for no load temperature by effect of change in pressure ratio, openings of orifice and double inlet valve. The model can also calculate the refrigeration power at given value of refrigeration temperature.

References:

[1] Gifford W E and Longsworth R C 1964 Pulse tube refrigeration Trans. ASME. **86** 264-8

[2] Mikulin E I, Tarasov A A and Shrebyonock M P 1984 Low temperature expansion pulse tube Adv. In Cryogenic Engineering Plenum Press **29** 629-37

[3] Zhu S, Wu P and Chen Z 1990 Double inlet pulse tube refrigerator-an important improvement Cryogenics **30** 514-520

[4] Wang C, Wu P Y and Chen Z Q 1992 Numerical modeling of an orifice pulse tube refrigerator Cryogenics **32** 785-90

[5] Wang C, Wu P Y and Chen Z Q 1994 Numerical analysis of double inlet pulse tube refrigerator Cryogenics **33** 526-30

[6] Ju Y L, Wang C and Zhou Y 1998 Numerical simulation and experimental verification of the oscillating flow in pulse tube refrigerator Cryogenics 38 **169-76**

[7] Wang C 1997 Numerical analysis of 4 K pulse tube coolers: part I. numerical simulation Cryogenics **37** 207-13

[8] Web reference: www.webbook.nist.gov/chemistry/fluid dtd. 20/01/2015

[9] Lu G Q and Cheng P 2000 Flow characteristics of a metering valve in pulse tube refrigerator Cryogenics **40** 721-7

[10] Desai K P 2003 Investigations of orifice pulse tube refrigerator PhD thesis 86

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