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EXPERIMENTAL STUDIES ON INLINE PULSE TUBE CRYOCOOLER

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***Abstract*: An Experimental Investigation on Inline Pulse Tube (PTC) was carried out using a Rotary Valve. Investigation is to study the cool down period for basic pulse tube model with varying speed of the rotary valve as well as the flow rate, using compressed air as working medium under a pressure of 6 bars. A no load cool down temperature of 258K was obtained.**

***Keywords*: Inline Pulse Tube, Rotary Valve, Vacuum Vessel, Vacuum Pump.**

I. INTRODUCTION

A Cryocooler is a refrigeration machine with refrigeration temperature below 123K and with a small refrigeration capacity. There are two types of cryocoolers: Recuperative type and Regenerator type. The former include the Joule Thomson cryocooler and the Brayton cryocooler. The latter include the Stirling type cryocooler and the Gifford-McMahon type cryocooler. These Cryocoolers as enumerated by Radebaugh (1995) are mainly used for cooling of the infrared sensors in the missile guided system and satellite based surveillance, as well as in the cooling of superconductors and semiconductors. The cryocoolers can also be used in other applications such as in cryopumps, liquefying natural gases, cooling of radiation shields etc..

A Cryocooler is a standalone cooler used to cool and maintain cryogenic temperatures by cycling certain gases. Using cryocoolers a very low temperature of about 20K and less can be achieved. The field of cryogenics advanced during World War II when scientists found that metals frozen to low temperatures showed more resistance to wear and was used for cooling infrared sensors to about 80K, for applications in tanks, airplanes and missiles. Refrigeration power range from 0.15W to about 2W.

The Pulse Tube belongs to the class of miniature cryogenic refrigerators usually referred to as cryocoolers. Commonly Stirling and Gifford-McMahon machines, operation depends on a regenerative gas expansion cycle but unlike these coolers the Pulse Tube is having no moving parts at low temperature and hence offers high reliability. In mid's 1960's the Gifford McMahon [1] developed a Basic Pulse Tube Refrigerator for research purpose and the dimensions of the Pulse Tube was 19mm dia x 30 cm long x 0.4mm thick and the regenerator dimensions with 19mm dia x 0.4mm thick with Iron and copper beads of different sizes of approximately #300 mesh and could attain a cooling temperature of 150K. Mikulin [2] showed that the efficiency of the pulse tube cryocooler could be increased by introducing a buffer reservoir to the warm end of the pulse tube through an orifice, this was the new constructional solution and was named as Orifice Pulse Tube Refrigerator and could obtain a cooling temperature of 30-36K. Garaway [3] have carried out experimental investigation on a miniature, high energy density, Pulse Tube Cryocooler, with a working pressure of 50 bars and helium as the working fluid. With an Inline configuration and inertance tube, they were able to reach a temperature of 80K with an operating frequency of 150Hz.

A) Pulse Tube Refrigerators

The pulse tube refrigerators (PTR) are capable of cooling to temperature below 123K. Unlike the ordinary refrigeration cycles which utilize the vapor compression cycle as described in classical thermodynamics, a PTR implements the theory of oscillatory compression and expansion of the gas within a closed volume to achieve desired refrigeration. Being oscillatory, a PTR is a non steady system that requires time dependent solution. However like many other periodic systems, PTR's attain quasi-steady periodic state (steady-periodic mode). In a periodic steady state system, property of the system at any point in a cycle will reach the same state in the next cycle and so on. A Pulse tube refrigerator is a closed system that uses an oscillating pressure (usually produced by an oscillating piston) at one end to generate an oscillating gas flow in the rest of the system. The gas flow can carry heat away from a low temperature point (cold heat exchanger) to the hot end heat exchanger if the power factor for the phasor quantities is favorable. The amount of heat they can remove is limited by their size and power used to drive them.

II. EXPERIMENTAL SETUP

Fig. 1 shows the Line Diagram of the complete assembly. The Compressed air is made to flow the Regenerator tube. The gas flow after the Regenerator is passed into the Pulse Tube. Vacuum is created in the Vacuum Vessel with the help of Two Stage Rotary Vacuum Pump. The Vacuum level in the vessel is measured by a Pirani Gauge.

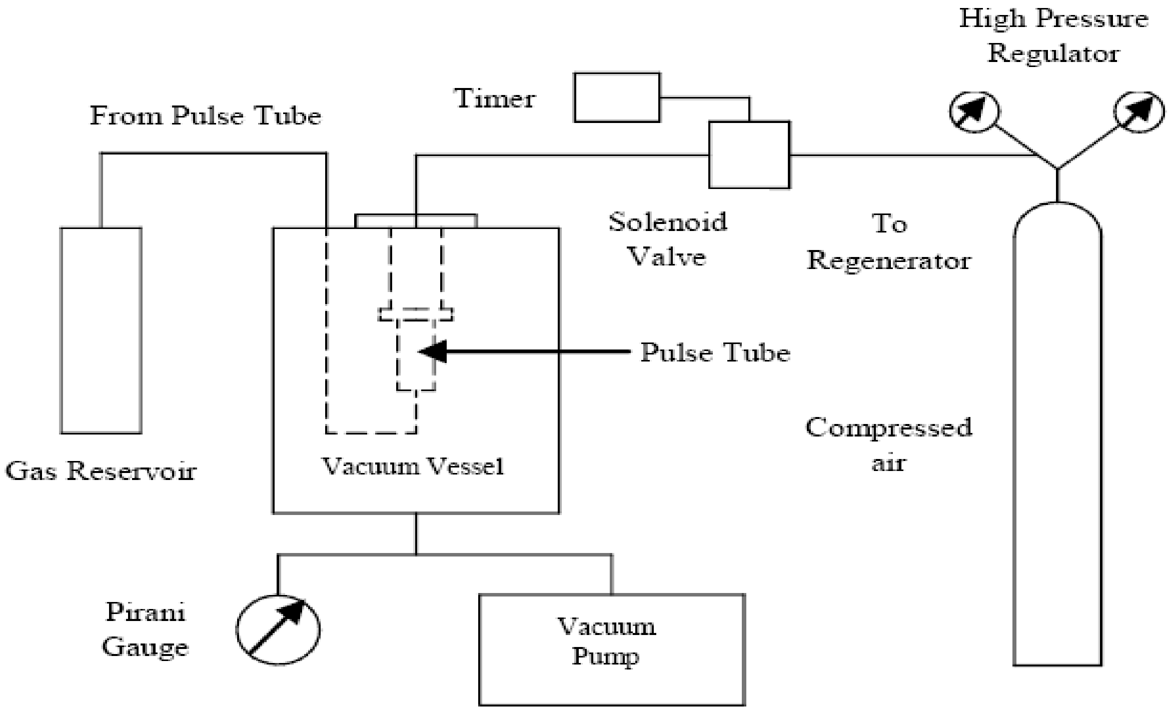

Fig. 1 Line Diagram of Complete Assembly

TABLE. 1 PULSE TUBE DESIGN

Sl. No.	Parts	Specification
1	Pulse Tube	7mm ID x 7.7mm OD x 42mm long
2	Regenerator	13mm ID x 13.7mm OD x 42mm long

Table. 1 shows the design and dimensional parameters of an Inline Pulse Tube Cryocooler. The Pulse Tube body and Regenerator are made of S.S 304 material and the regenerator house is stacked with #400 mesh of Stainless Steel. Preparation of circular mesh screens posed a challenging task. Suitable die and punch were made to get the correct geometry circular punch. Cold End Collar is of S.S and was covered by a Collar Ring which was made by Copper material so that it can retain the cold end temperature for a period of time.

Fig. 2. Shows the complete assembled view of entire Inline Pulse Tube Cryocooler. The Pulse Tube was fabricated as per the design as shown in Fig. 2. Vacuum created in the vessel minimized heat leakage to the cold head from surrounding environment. Vacuum level at least 10^{-2} torr was obtained using two stage rotary vacuum pump. The Vacuum Vessel of

capacity 3.55 liters is fabricated from S.S 304 material. Vacuum level of was measured using a pirani gauge with analogue display.

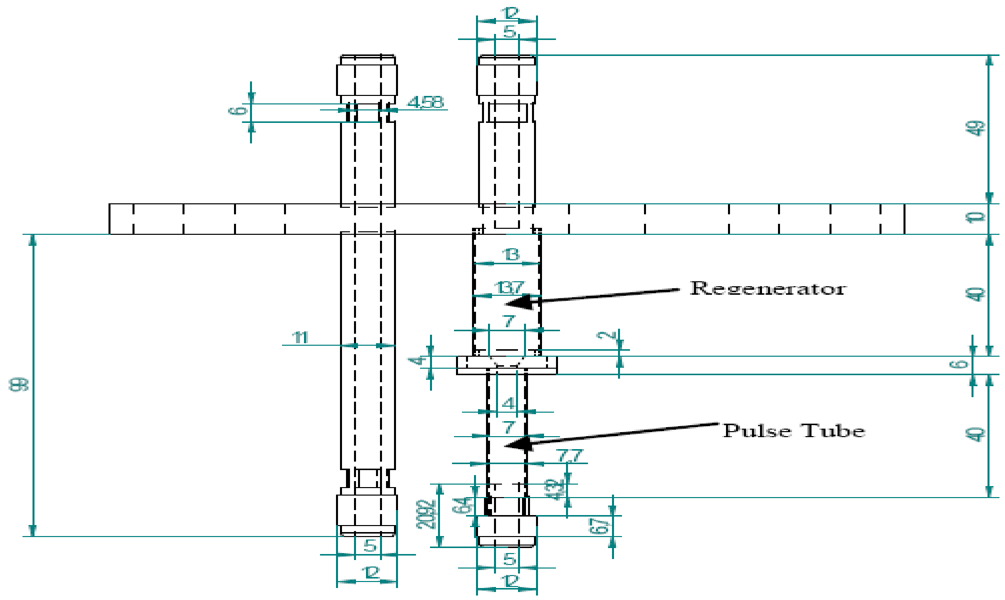

Fig. 2 Schematic of the complete assembly

A) Rotary Valve

Apart from timer controlled solenoid valve for generating the pulses to the pulse tube, a Rotary Valve was also developed which could operate at much higher pressure of 20 bars as shown in Fig. 3. Rotary valve have been used so far. This valve essentially consists of circular disc made out of low friction material such as graphite filled or bronze filled PTFE with two semi circular grooves on its end face. Two port holes are drilled axially for gas passage. The disc is housed inside a cylindrical chamber and driven at low speed with help of low speed D.C. motor. External connections for gas supply are provided on either side of the disc. The rotation of rotor disc results in alternate changeover of the gas supply from compressor to pulse tube and in the first half rotation of the disc and gas exhaust from the pulse tube to the exhaust or back to the compressor in the second half rotation of the disc. Hence in one rotation gas supply to the pulse tube and exhaust from the pulse tube takes place. The main advantage of Rotary Valve is that it can withstand high pressures and operate at high flow rate.

The Rotary valve was fabricated as per the design. The material chosen was Stainless Steel(S.S) 304 for both bottom and Top Flange. For pressure oscillation a graphite filled PTFE(Poly Tetra Fluoro Ethylene) or generally Teflon was chosen. Two no's of PTFE's were fabricated as shown in Fig. 4, (a) with higher flow rate and (b) with lower flow rate. PTFE was mounted to the shaft with the help of a Teflon Bottom made of S.S. Shaft of OD 10mm was fixed into the Teflon bottom (PTFE) through threading and Teflon bottom was hold by PTFE through screw fasteners.

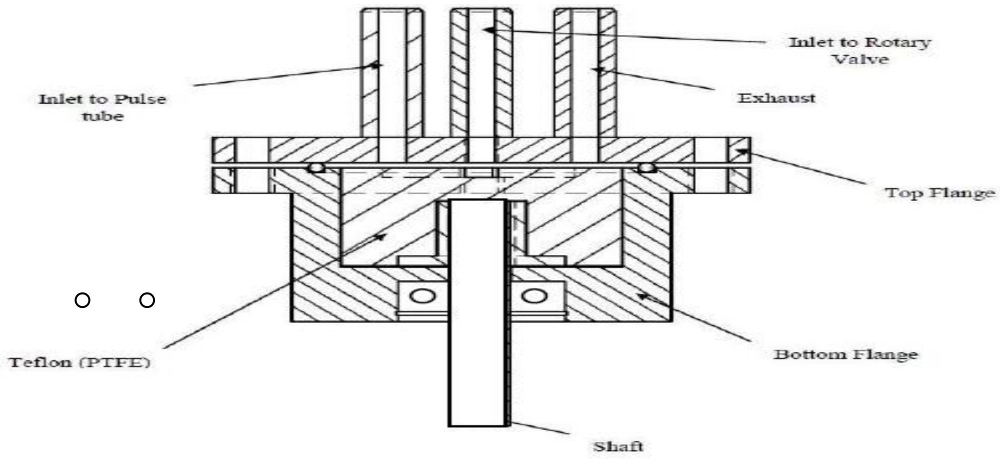

Fig. 3. Schematic of Rotary Valve

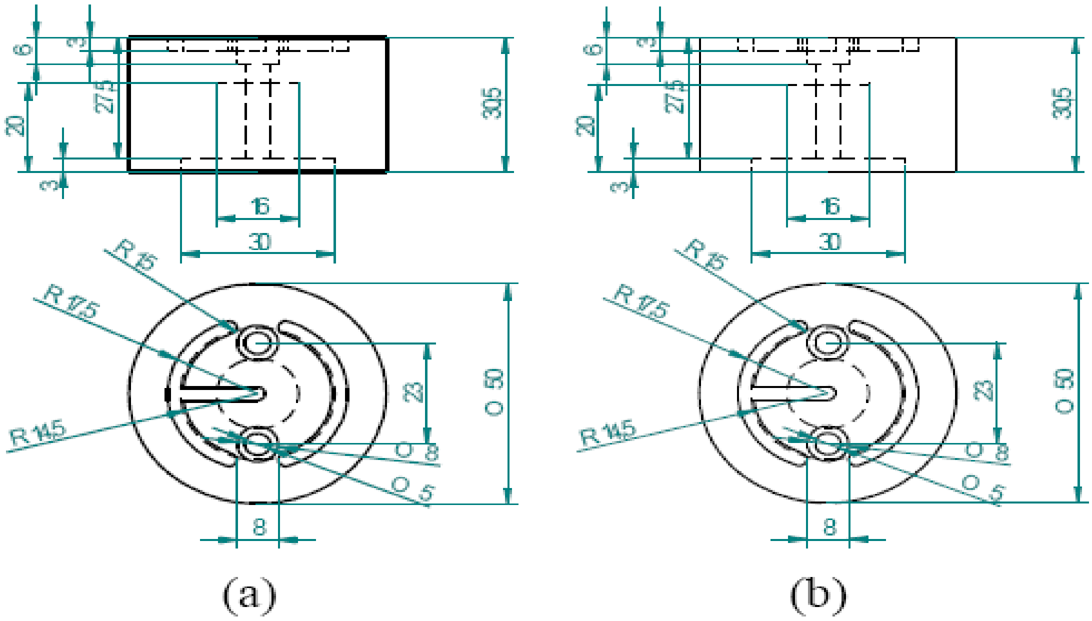

Fig. 4 (a) PTFE of More flow rate (b) PTFE of Less flow rate

The Rotary valve speed was controlled through a variable speed Permanent Magnet DC Shunt motor as shown in Fig. 5. Motor was connected to shaft of Rotary valve through castling couplings. The speed of the motor was varied with the help of Speed controller.

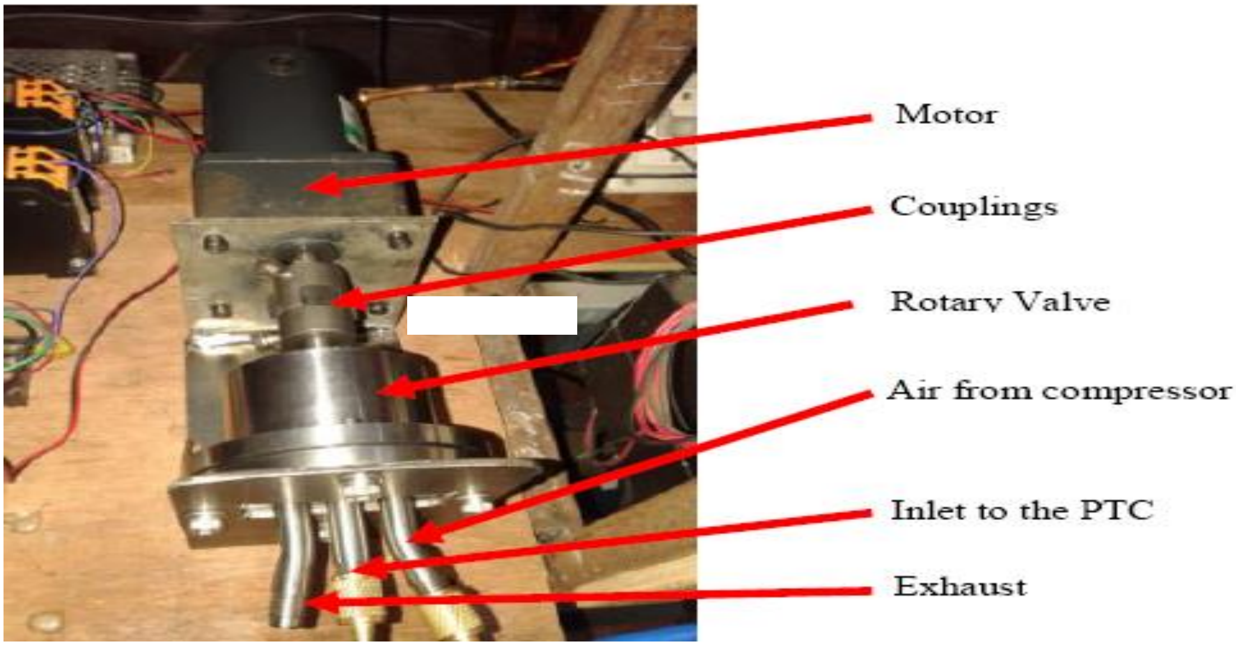

Fig . 5 Pictorial view of Rotary Valve integrated to a motor

After complete assembly of rotary valve was made, it was supported by a bracket and fixed. The connections were made suitably and the experiment was carried out.

III. RESULT AND DISCUSSION

Investigation was carried out on the coaxial pulse tube with air as working medium. The experimentation was carried out on different speeds of Rotary valve and with different PTFE's so that flow rate was altered. After careful investigation at 6 bar air pressure, it was noted that the cooling capacity was good at maximum speed of Rotary Valve and with low Flow rate PTFE(Fig .4 (b)). Fig .6 shows the cooling capacity at different speeds.

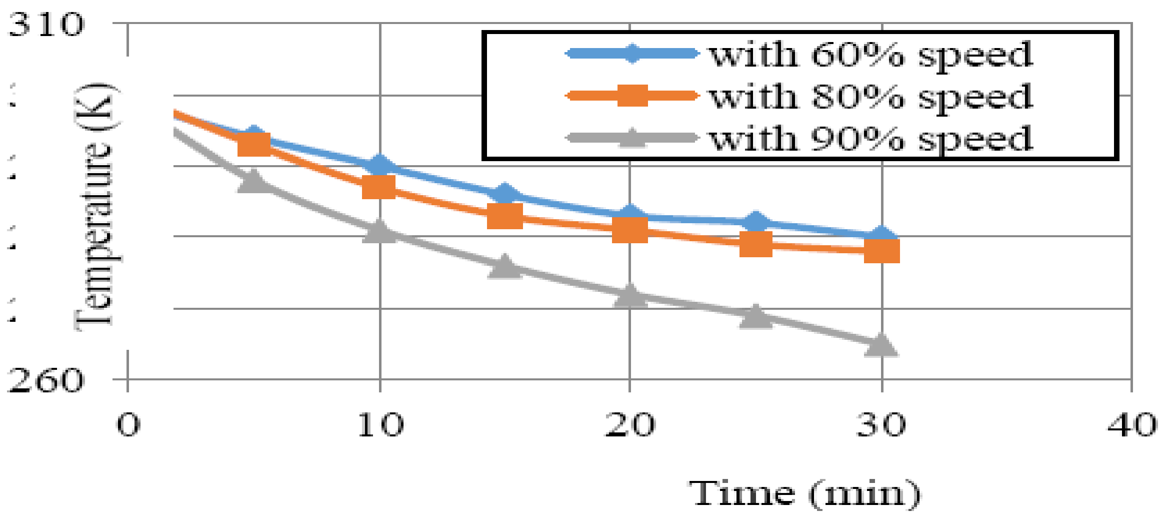

Fig. 6 Time to temperature graph comparing the results of Inline PTC with different speeds of rotary valves

The experiment was carried out by installing the Inline Pulse Tube in the vacuum chamber and maintaining 0.03mbar of vacuum pressure. The experiment was carried out at 6 bar air pressure with less flow rate PTFE and with 90% speed of Rotary Valve.

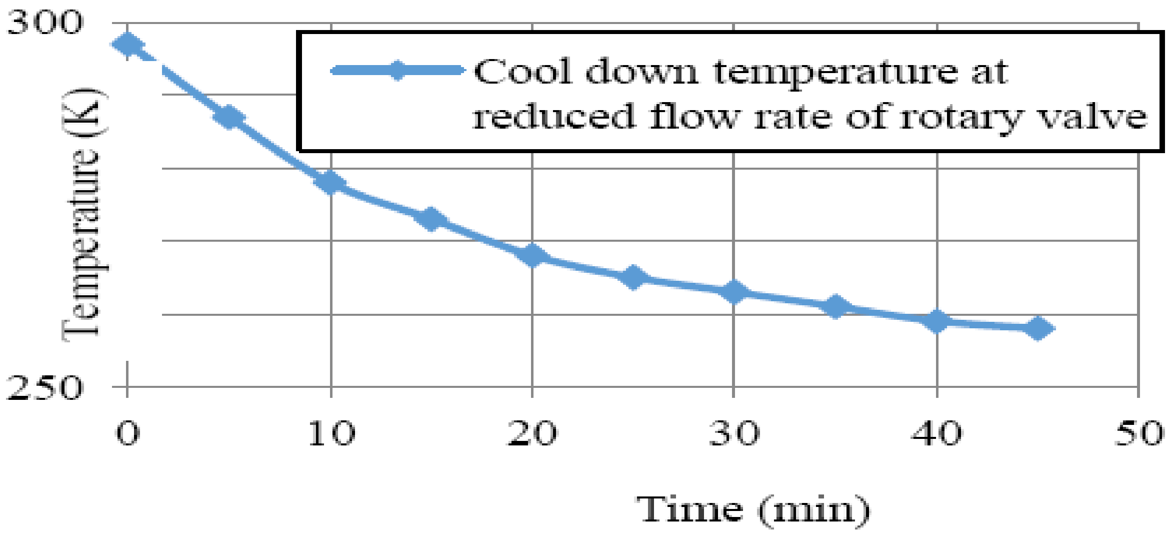

Fig. 7 Time to Temperature graph of Inline Pulse Tube

The cooling capacity of 258K at no load condition was obtained within a short period of time as shown in Fig.7.

IV. CONCLUSIONS

A Inline Pulse Tube driven by Rotary Valve has developed and demonstrated successfully. A no load temperature down to 258K could be attained in a reasonably short time. Much lower temperature could have been attained if the wall thickness of the Pulse Tube and the regenerator tubes were at least 0.3mm.

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REFERENCES

[1] W.E.Gifford and R.C.Longsworth, "Pulse tube Refrigeration", Trans. ASME:JI. of Engg. For Industry, 86 (1964) page 264-268.

[2] E.I.Mikulin et al, "Low temperature expansion Pulse Tubes", Adv. in Cryogenics Engg. 29, (1984) page 629-637.

[3] Garaway, Z.Gan, P.Bradley, A.Veprik, and R.Radebaugh, "Development of a Miniature 150Hz Pulse Tube Cryocooler".

[4] Ray Radebaugh, "Development of the Pulse Tube Refrigerator as an Efficient and Reliable Cryocooler", Proc.Institute of Refrigeration (London) 1999-2000.

[5] D.L.Gardener and G.W.Swift, "Use of Inertance in Orifice Pulse Tube Refrigerators", Cryogenics 37, (1997) page 117-121.

[6] Q.Cao, Z.H.Gan, G.J.Liu, et al, "Theoretical and Experimental Study on a Pulse Tube Cryocooler Driven with a Linear Compressor".

[7] V.Venkatesh and R.Chandru, "Experimental Study on a Pulse Tube Refrigerators".

[8] Z.H. Gan, B.Y. Fan, Y.Z.Wu, L.M.Qiu, X.J.Zhang, G.B.Chen, "A Two-Stage Stirling-Type Pulse Tube Cryocooler with a Cold Inertance tube", Cryogenics 50(2010) page 426-431.

[9] L.M. Qiu, X.Q. Zhi, L.Han, Q.Cao, Z.H.Gan, "Performance improvement of multi-stage pulse tube cryocoolers with a self-precooled pulse tube", Cryogenics 52(2012) page 575-579.

[10] L.M. Qiu, Y.L. He, Z.H.Gan, G.B.Chen, " A single-stage pulse tube cooler reached 12.6K" Cryogenics 45(2005) page 641-643.

[11] Haizheng Dang, Libao Wang and Kaixiang Yang, "10W/90K Single-stage pulse tube cryocoolres", Cryogenics 52(2012) page 221-225.

[12] J.Y.Hu, J.Ren, E.C.Luo, W.Dai, "Study on the inertance tube and double-inlet phase shifting modes in pulse tube refrigerators", Energy conversion and management 52(2011) page 1077-1085.

[13] S.Kasthurirengan, G.Srinivasa, G.S.Karthik, D.S.Nadig, U.Behera, K.A.Shafi, "Experimental and theoretical studies of a two-stage pulse tube cryocooler operating down to 3K", International journals of Heat and Mass Transfer 52(2009) page 986-995.

[14] Yang Luwei, Zhou Yuan, Liang Jingtao, " Research of pulse tube refrigerator with high and low temperature double-inlet", Cryogenics 39(1999) page 417-423.

[15] G.Popescu, V.Radcenco, E.Gargalian, P.Ramany Bala, " A Critical review of pulse tube cryogenerator research", International Journals of Refrigeration 24(2001) page 230-237.

[16] Haizheng Dang, "40K Single-stage coaxial pulse tube cryocoolers", Cryogenics 52(2012) page 216-220.

[17] X.B. Zhang, K.H.Zhang, L.M.Qiu, Z.H.Gan, X.Shen, S.J.Xiang "A Pulse Tube Cryocooler with a cold reservoir", Cryogenics 52(2012) (article in press).

[18] B.J.Huang and T.M.Tzeng, "Performance characteristics of Pulse Tube refrigerators", Cryogenics 33(1993), page 516-520.

[19] Ray Radebaugh, " Pulse Tube Cryocoolers for cooling Infrared Sensors", National Institute of Standards and Technology Boulder, Colorado 80303 USA.

[20] E.D.Marquardt and Ray Radebaugh, "Pulse Tube Oxygen Liquefier", Cryogenic Engineering 45(2000), page 457-464.

[21] M.V. Tendolkar, K.G. Narayankhedkar & M.D. Atrey, "Experimental Investigation on 20K Stirling-Type Two-Stage Pulse Tube Cryocooler with inline Configuration".

[22] Zhu Shaowei, Wu Peiyi and Chen Zhongqi, " Double inlet pulse tube refrigerators: an important improvement", Cryogenics 30(1990), page 514-520.