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AN INVESTIGATION ON COAXIAL PULSE TUBE CRYOCOOLER

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Abstract: **An Experimental Investigation on a Coaxial Pulse Tube with Basic Pulse tube as well as Double inlet Orifice arrangement has been carried out with electrically operated solenoid valve driven by a Pulse Timer. Investigation is to study the cool down period for Basic Pulse Tube model and Double Inlet configuration with varying Pulse timing. With Air as working medium under a pressure of 6bars, a cool down capacity of 239K, With Nitrogen as working medium under a pressure of 15 bars, a cool down capacity of 229K is obtained on no load condition and a cool down capacity of 261K in Double inlet configuration with an operating pressure of 6bars of air is achieved.**

Keywords: **Co-axial Pulse Tube, Pulse Timer, Vacuum Vessel, Vacuum Pump.**

I. INTRODUCTION

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.

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 regenerative type. The former includes the Joules Thomson cryocooler and the Brayton cryocooler. The latter includes the Stirling type cryocooler and the Gifford-McMahon type cryocooler. These cryocoolers as enumerated by Radebaugh (1995), are mainly used for cooling of the infrareds 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..

The pulse tube belongs to the class of miniature cryogenic refrigerators usually referred to as cryocoolers. In common with Stirling and Gifford-McMahon machines, operation depends on a regenerative gas expansion cycle but unlike these coolers the pulse tube has no moving parts at low temperature and hence offers the potential for 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 30cm 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. and 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. D.L.Gardener and G.W Swift [6] gave the importance on use of inertance in Orifice Pulse Tube Refrigerators. The phase shift between oscillating pressure and oscillating velocity at the cold end is determined in part by the purely resistive nature of the Orifice Pulse Tube Refrigerator, they showed the Phase shift between the velocity and pressure can be shifted to more efficient Stirling Valves by adding an "Inertance" in the series with Orifice. Use of an Inertance is significantly beneficial only when the gross cooling power is Significantly Large.

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, PTRs 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 of Nitrogen is made to flow the Regenerator tube. The gas flow after the regenerator is passed into the Pulse Tube. The Vacuum is created in the Vacuum Vessel at the bottom with the help of Two Stage Rotary Vacuum Pump. The Vacuum level in the vessel is measured by a Pirani Gauge.

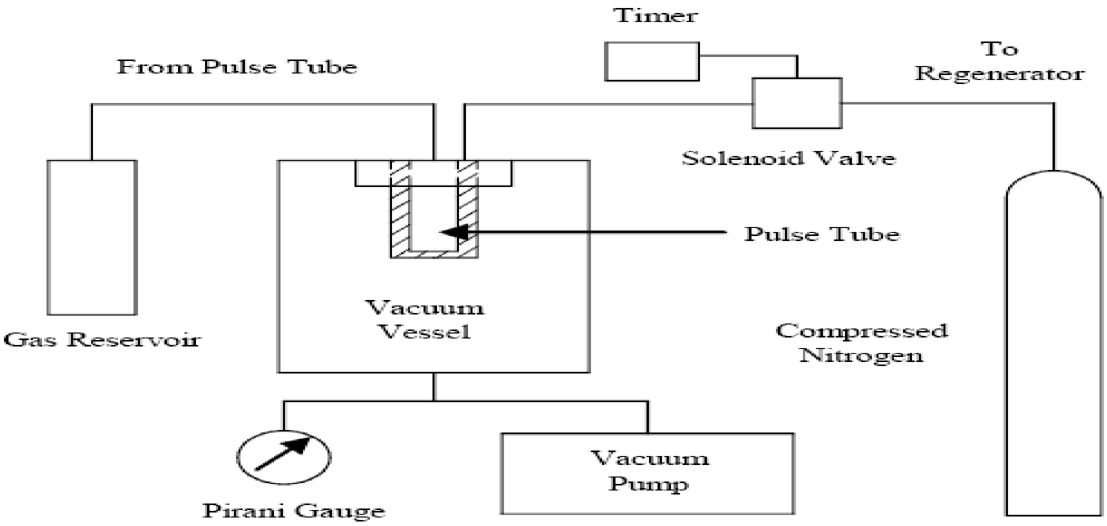


Fig. 1 Line diagram of complete assembly

TABLE.1 PULSE TUBE DESIGN

Sl no	Parts	Specification
1	Pulse Tube	12mm ID x 13mm OD x 0.5mm thick x 105mm long
2	Regenerator	28.5mm OD x 27mm ID x 0.75mm thick x 108.5mm long
3	Cold End Cap	27mm ID x 32mm OD x 6mm thick

Table. 1 shows the design and dimensional parameters of an Coaxial 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 S.S. Preparation of annular mesh screens posed a challenging task. Suitable die and punch were made to get the correct geometry annular punch. Cold End Collaring is of Copper material so that it can retain the cooling temperature for a period of time.
Fig. 2. Shows the complete assembled view of entire Coaxial Pulse Tube Cryocooler.

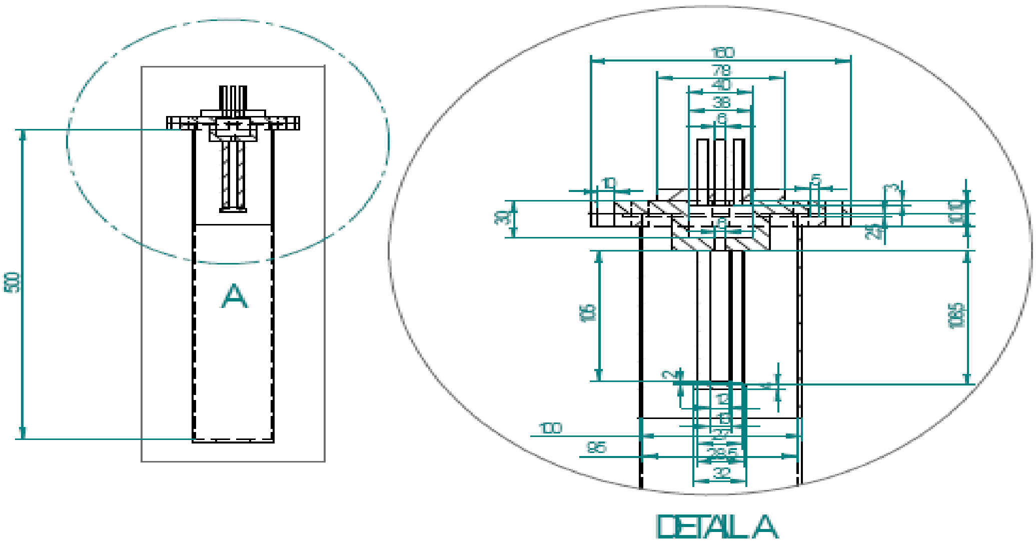
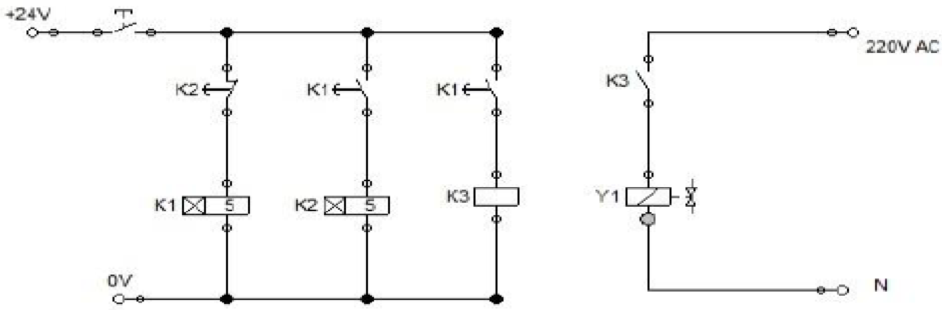


Fig. 2 Schematic of the complete assembly

Vacuum created in the vessel minimized heat leakage to the cold head from surrounding environment. Vacuum level at least 10^{-2}torr was used for this purpose. The Vacuum vessel of capacity 3.55 liters is fabricated from S.S 304 material. The dimension of the vacuum chamber are 95mm ID x 100mm OD x 500mm long. The vacuum pump was connected to the vacuum vessel. Q couplings of the flanges are connected using neoprene rubber tubes of 19mm ID. Vacuum level of the order of $5x10^{-3}$ torr could be obtained using this arrangement. Vacuum level was measured using a pirani gauge with analogue display.

A. Pulse Timer

Periodic gas pulses was generated using the Pulse timer. Working gas to the Pulse Tube cooler is supplied through a high pressure 2/3 way normally closed single solenoid valve operating on AC 220V supply is controlled by a pulse timing arrangement as shown in Fig. 2. The function of this unit is to control the opening and closing of solenoid valve which in turn controls the air/gas supply to the system. Fig. 3 shows the pictorial view of Pulse Timer Circuit.



K1 on delay Timer Relay coil set for 10 sec

K2 on delay Timer Relay coil set for 15 sec

Fig. 3 Pulse Timer Circuit.

DC power supply is used to convert the 230V AC main supply into 24V DC output which is further utilized by relay, timer relay. Two 'On delay timers' are used to control the opening and closing of the Relay switch. On delay Timers are provided with regulators using which the opening period and closing period of the relay contact can be controlled independently. Thus makes the system more versatile. Relays are switch contacts which is operated by the on delay timers, this in turn controls the opening and closing of the solenoid valve. Thus, this has a advantage over the conventional rotary valve in which the 'On' and 'Off ' period can be varied independently.

The gas supply to the system was achieved by connecting the solenoid valve to a Nitrogen gas cylinder through a high pressure two stage regulator which enables to carry out investigation up to 25 bar. The operating pressure in the pulse tube was measured using a pressure gauge.

Temperature at the cold end and the warm end was measured using chromal alumal thermocouples located at the two ends of the pulse tube and leads were taken out of the vacuum vessel through glass to metal seals located on the flange. The output of the thermocouple was measured with the help of a digital thermometer.

III. RESULTS AND DISCUSSION

Investigation was carried out on the coaxial pulse tube with working medium as compressed air and Nitrogen gas at high pressure. The experimentation was carried out for different pulse timing but at the rate around 70 pulses the results obtained were encouraging. Hence the pulse timer was set to 70 pulses for further trials. Cold end temperature were noted at regular intervals of time. As the system stabilizes and steady state is reached the temperature measurements were made. At no load cool down characteristics for Basic Pulse Tube With compressed air of pressure 6 bars could attain a temperature of 239K, as shown in Fig.4.

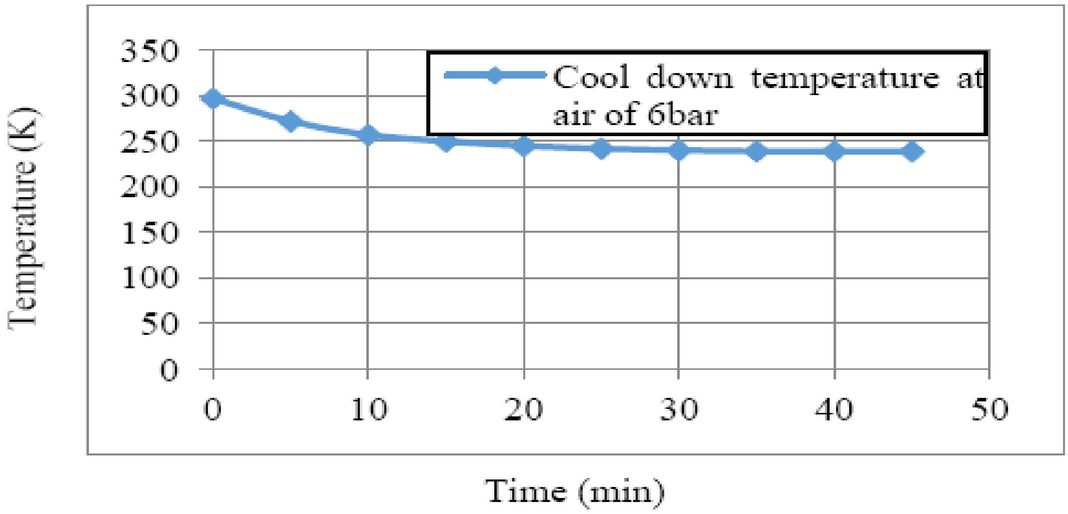


Fig. 4 Time to temperature graph showing the cooling temperature of Basic Pulse Tube with air as working medium.

Next the connection were modified for investigating double inlet configuration with same pressure of the compressor and the steady no load temperature at the cold end was 261K, as shown in Fig.5.

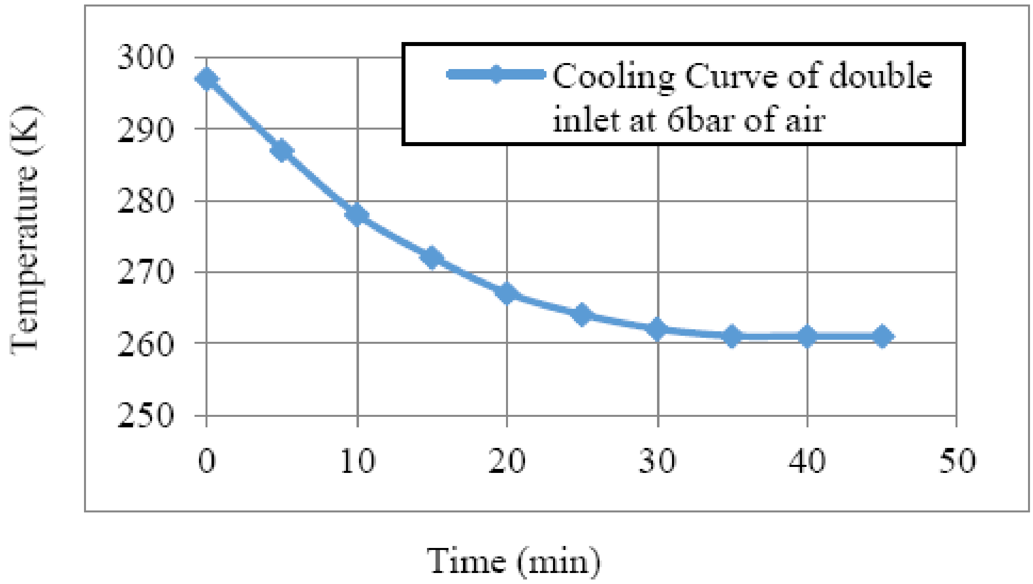


Fig. 5 Time to temperature graph showing the cooling temperature of Double inlet Pulse Tube.

Since the compressor was unable to operate at higher pressure, high pressure nitrogen gas was used from the cylinder at the required pressure with the help of a high pressure regulator. Supply pressure up to 15 bar was maintained to the pulse tube. A cooling temperature of 229K was achieved as shown in Fig.6.

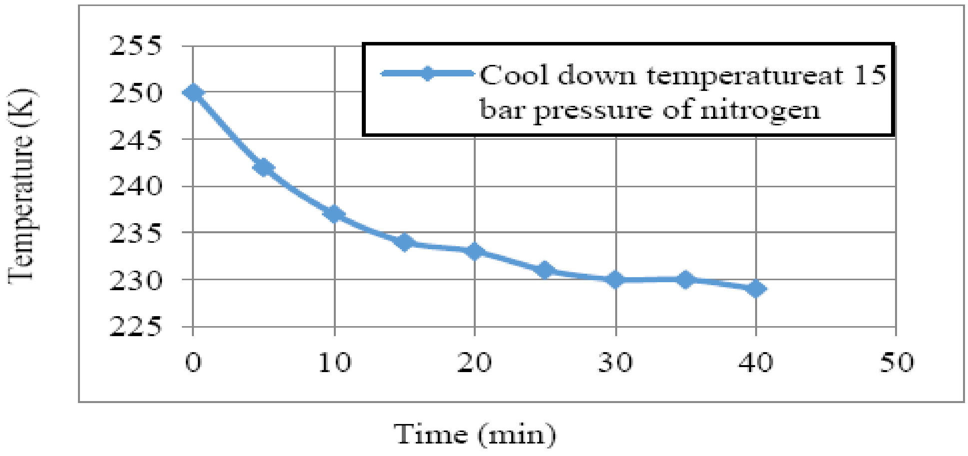


Fig. 6 Time to temperature graph showing the cooling temperature of Basic Pulse Tube with Nitrogen as working medium.

Cool down characteristics at no load conditions at the cold end show similar trend for the three cases mentioned above. Transient cooling takes place at the cold end which is well protected against convection heat gain from the surroundings in the vacuum vessel. Cool down time for direct pulse tube with air at 6 bar pressure took 45 minutes under vacuum level of about 5 x 10^{-2} torr in the vacuum vessel. It was observed with vacuum level deteriorating, the steady state temperature attained was higher at least by 5 to 10^{0}C.

Investigation carried out using Nitrogen gas at 15 bar was quite encouraging. Temperature down to 229K at no load conditions. However, lowest temperature reached with Double inlet Pulse Tube was discouraging, that is cold end temperature was far higher than expectation. This is attributed to the fact the needle valve used for controlling the orifice was not compatible. Right type of needle valve was not available readily. In fact this version should have given much lower temperature due to the possibility of phase shift of gas piston in the pulse tube.

IV. CONCLUSIONS

A coaxial Pulse Tube driven by electrical pulse timer has been developed and demonstrated successfully. Both compressed air at 6 bar and Nitrogen gas at 15 bar were used as the working medium. A no load temperature down to 229K could be attained in a reasonably short time.

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