Studies on a Single Stage GM type Pulse Tube Cryocooler Using an Indigenous Helium Compressor

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A GM type single stage Pulse Tube Cryocooler has been designed, fabricated and operated with an indigenous Helium Compressor developed using a 2 kW Freon Compressor suitably modified with cooling arrangements for oil and gas. Using a regenerator of 19 mm od and 250 mm length, housing 1850 wire screens of 250 mesh size, a lowest temperature of 37.5 K and a refrigeration power of ~10W at 77 K have been obtained for a Pulse Tube of 14 mm od and 300 mm length, with an indigenous rotary valve. The performances of this configuration have been compared with those when operated using a 3 kW imported helium compressor. Studies show that due to the increased pressure ratio (of high to low pressure) of the indigenous compressor, ~ 50% more cooling power is obtained in this case. A comparative study of results relating to, cool-down, pressure waveform, cooling power, and the angular variation of cold end temperature, when the system is operated with these compressors, is presented here.

INTRODUCTION

Cryocoolers or Cryorefrigerators produce the required refrigeration power at specific low temperature. Several types of cryocoolers based on different cycles such as GM, Stirling and Pulse Tube have been used for a variety of applications such as sensor cooling, radiation shield cooling, cooling of superconducting magnets, cryopumping etc. Of the above, Pulse Tube Cryocoolers [1-2] are preferred due to the absence of moving parts at cryogenic temperatures, which leads to increased reliability and long-term performance. In a Pulse Tube cooler, the high and low pressures from a helium compressor are alternately applied to the empty Pulse Tube through a regenerator, using a rotary valve.

We have developed a single stage Pulse Tube experimental system that uses an imported water-cooled helium compressor of 3 kW along with an indigenous rotary valve. Also, an indigenous helium compressor (using a 2kW reciprocating type Freon compressor) has been developed and the experimental studies have been repeated using the latter. In this paper, the performances of the Pulse Tube cooler with these compressors are compared.

EXPERIMENTAL SETUP

The schematic of experimental set up is shown in Figure 1. The Pulse Tube and the Regenerator housings are made up of AISI 304 stainless steel. The dimensions of Pulse Tube are 14 mm od., 250 mm length, while those of the Regenerator are 19mm od. and 210 mm length. The heat exchangers and the flow straighteners are made of copper of electrolytic grade. The regenerator matrix is made of stainless steel wire meshes of size 250 and contains ~ 1850 meshes [3-4]. The warm end of the Pulse Tube is connected to a heat exchanger through which cold water is circulated to maintain it at ambient temperature. Both the Pulse Tube and the regenerator are mounted to the top flange of the vacuum jacket by o-ring seals. The cold ends of the Pulse Tube and regenerator ends in a copper heat exchanger with indium seals.

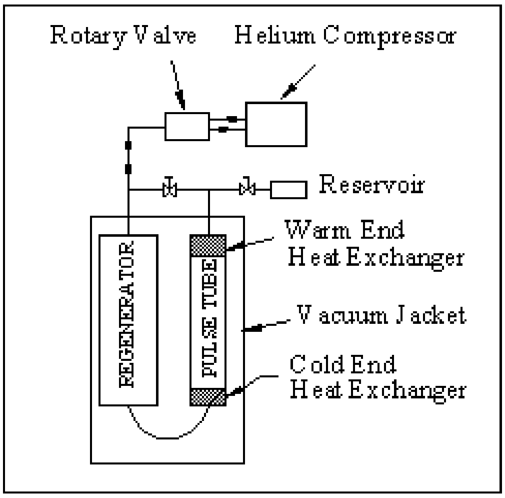

Figure 1 Schematic of Single Stage Pulse Tube Cryocooler

The Helium compressor serves as the source for high and low pressure gas supply to the Pulse Tube. The design of the setup was such that the Pulse Tube can be operated either in basic, or orifice or double inlet mode with the help of needle valves (Swagelok) along with a stainless steel buffer volume of 0.5 litres.

Platinum sensors (PT100) have been used as temperature sensors while piezoelectric transducers (KPY47R, Siemens) are used as pressure sensors. The vacuum jacket housing the Pulse Tube and the regenerator is fixed to a rotatable horizontal axle, by which the orientation of the Pulse Tube with respect to gravity can be varied from 0^0 to 180^0. At the cold end of the Pulse Tube, a manganin heater of 62.5 Ω is fixed and energized by using a power supply at constant current mode.

Experimental studies have been conducted with two different helium compressors (a) An imported 3kW rotary type water-cooled helium compressor (RICOR) and (b) An indigenously developed 2kW reciprocating type helium compressor (using a Tecumseh make refrigeration compressor). Before the discussion of the experimental results, some details of this development are presented below.

INDIGENOUS COMPRESSOR DEVELOPMENT

The main purpose of this development is the absence of any local suppliers to provide Helium gas compressors. Also, most of the imported Helium compressors are based on conventional refrigeration compressors with suitable oil / gas cooling arrangements for use with helium gas. In the Pulse Tube system, the major cost is that of the Helium compressor. Hence indigenisation of this component will considerably reduce the total cost of the system. Further, such a compressor may also be used for other gases.

Adaptation of refrigeration compressor for helium gas

When a conventional Freon compressor is used for refrigeration, the cooling of the compressor occurs by the cold refrigerant itself. However, when Freon is replaced by helium gas in the above, the heat of compression considerably increases due to increase in the ratio of specific heats for helium (γ_{He} ~ 1.67) This causes (a) considerable heating of the compressor and (b) cracking of the oil in the compressor. To take care of these, methods for cooling either the compressor body as a whole or the lubricant oil in the compressor should be adopted. In the present development, both the above methods have been used.

Cooling of compressor body by cold water

The compressor body is wound tightly with 3/8''o.d. copper pipe and bonded with metal paste. Cold water is circulated through the copper pipe to reduce the compressor body temperature.

Cooling the lubricant oil of the compressor

The cooling of the oil can be carried out either externally or internally. We have used the external cooling arrangement as shown in Figure 2 and is described below.

A copper pipe welded at the bottom of the compressor and the oil from this pipe collects in a buffer vessel and is cooled to ambient temperature. This oil is fed back to the compressor by high-pressure helium with the help of two solenoid valves A and B operated by an electronic timer. Due to the cyclic opening and closing of the solenoid valves the oil is taken from the bottom of the compressor and is circulated back to the compressor.

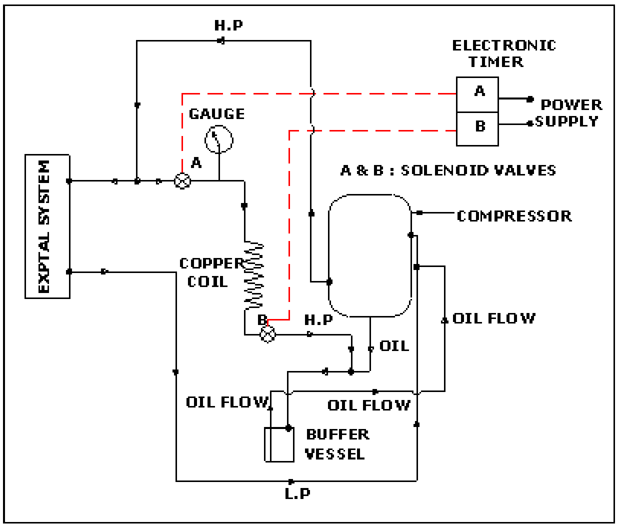

Figure 2: Schematic of modified Freon compressor for helium gas Indicating oil and gas flow circuits

RESULTS AND DISCUSSION

Cool down behaviour

The cool down behaviour of the Pulse Tube refrigerator is similar when operated with either of the compressors. The typical cool down is compared for the 14 mm Pulse Tube in the double inlet mode at 2.3 Hz in Figure 3. The lowest temperature reached is ~ 43.8 K, for the imported compressor and ~ 42.5K for the indigenous compressor. The typical cool down time is marginally higher for the imported compressor by about 10 minutes.

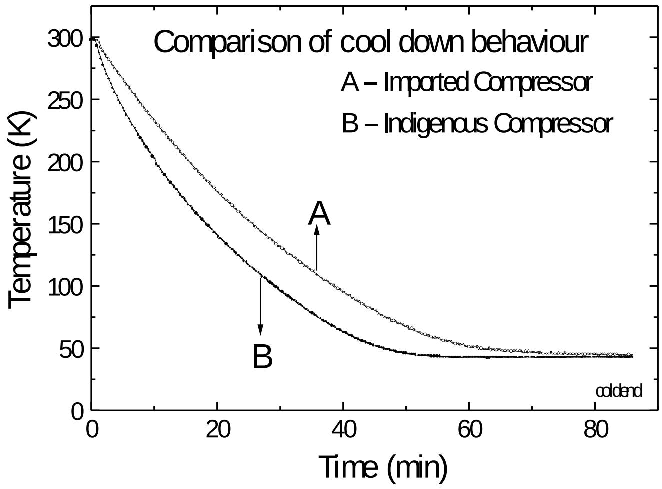

Figure 3 Cool down behaviour of Pulse Tube Refrigerator

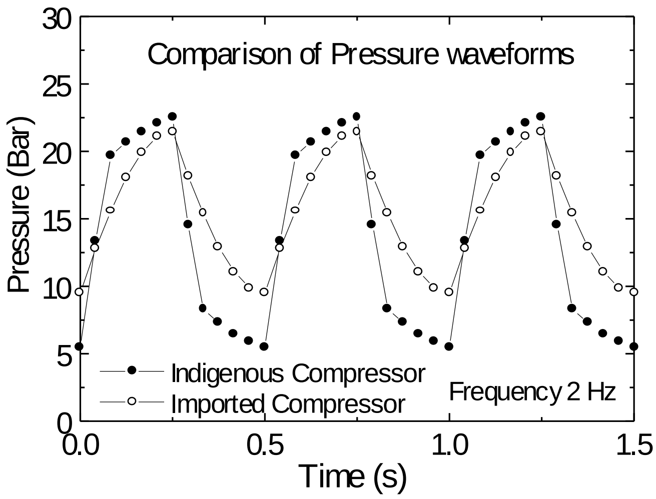

Figure 4 Comparison of pressure waveforms of compressors

Pressure ratio

The pressure ratio is the ratio of high to low pressure at the outlet of the rotary valve and is shown in Figure 4. The pressure ratio is 22.5 / 5.5 for the indigenous compressor and 21.5 / 9.5 for the imported compressor. The pressure waveform is more to trapezoidal for the indigenous compressor, where as it is nearly sinusoidal for the imported compressor. It is observed that the increased pressure ratio and the modified waveform have a significant effect on the performance of the Pulse Tube refrigerator.

<u>Refrigeration Power of the Pulse Tube</u>

The cooling power is measured by applying a given heat load and monitoring the steady temperature reached at the cold end of the Pulse Tube. The heat load is raised in known steps up to 10W. The typical experimental results with indigenous and imported helium compressors for the 14mm Pulse Tube are shown in Figure 5. It is observed that at 77 K, refrigeration powers of about 7W and 10 W are achieved for the imported and indigenous compressors respectively, indicating clearly the effect of increased pressure ratio.

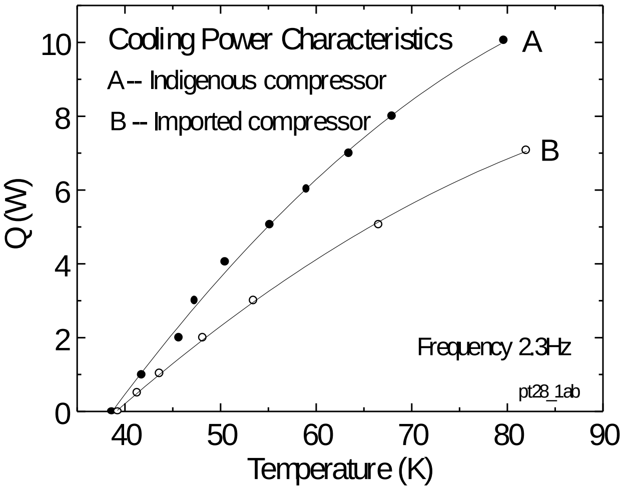

Figure 5 Cooling power characteristics of PTR

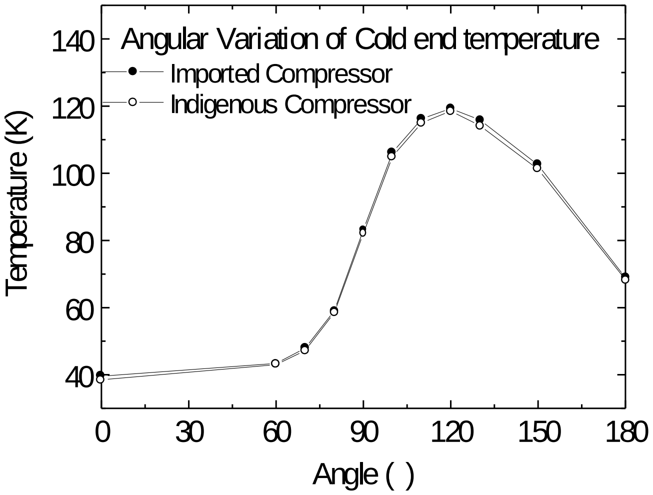

Figure 6 Angular variations of cold end temperature of PTR

<u>Angular variation of cold end temperature of PTR</u>

Due to the convection effects occurring in the Pulse Tube, the cold end temperature depends on the orientation of the Pulse Tube with respect to the gravity. The typical angular variation behaviour of 14 mm Pulse Tube is compared for both the compressors in Figure 6. It is observed that the behaviour is nearly the same, except that the maximum temperature at 120° is somewhat lower in the case of indigenous compressor.

CONCLUSION

This work discusses the performances of the single stage Pulse Tube refrigerator, when operated with imported and indigenous helium compressors. The results show that higher the pressure ratio and more trapezoidal the pressure waveform, higher is the cooling power of the Pulse Tube refrigerator, as has been observed in our studies with the indigenous helium compressor.

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