CLOSED CYCLE HELIUM CRYOREFRIGERATOR

Several scientific and technological applications require low temperatures in the range of 10 K - 30 K, with rather modest heat load requirements of a few watts. One important example is cooling of devices like infra-red optical detectors, parametric amplifiers and cryopumps. Closed cycle Helium cryorefrigerators are particularly convenient and economical systems for this purpose as they dispense with the need of rather expensive liquid Helium plant and the problems associated in the handling of liquid Helium.

Considering the immense potential of these cryorefrigerators, development of closed cycle Helium cryorefrigerators has been taken up at CAT. The prototype cryorefrigerator developed at CAT can produce temperatures down to 20 K with a heat load of 2.5 W (at 20 K), for a continuous operating period of ~12 hour. This operational period may be sufficient for some experiments, and interested users may procure these cryorefrigerators from CAT. The reasons limiting the operational time of these cryorefrigerators have been identified and efforts are on to increase the continuous operating period of this machine to several hundred hours. This article briefly describes the basic principle, design features, performance characteristics and the current efforts to improve the system based on Gifford McMahon cycle.

Perhaps the simplest method for producing low temperature is by Joule-Thomson (J-T) expansion, where the gas is made to expand from a high pressure region to a low pressure region through a constriction. This method however requires that the expanding gas be below its inversion temperature. Helium is the only gas that can produce temperatures below 20K. It has an inversion temperature of 40K. Use of J-T expansion for producing low temperature using Helium gas will, therefore, require its precooling below 40K. The gas can also be cooled by being made to do external work. In contrast to J-T expansion the later method always results in lowering of temperature and does not require any precooling. This work can be done in a expansion engine or turbine as in Cloude cycle. The systems based on this cycle have high refrigeration efficiency (~25%, for air liquefication systems), but are complicated to fabricate as they operate at higher rpm, and because the required seals, valves etc. work at low temperature. Further they are very bulky and are not suitable for cooling small systems. For cooling of small size detectors /amplifiers, a more compact system was designed and first reported by Gifford and McMahon in 1959. Although it has very small efficiency (for practical 4.2K refrigerators ~4%), this system is widely used for small capacity cryorefrigerators.

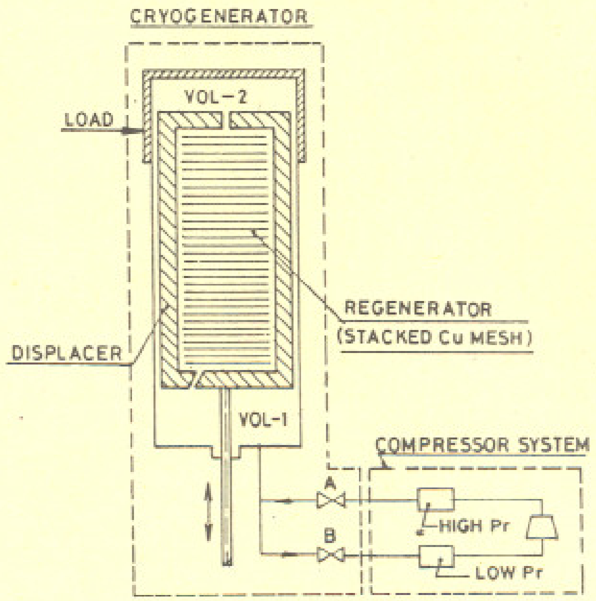

Fig. 1. Schematic diagram of a Gifford McMahon closed cycle cryorefrigerator.

Apart from compactness it works at a lower rpm (60 - 150 rpm), which results in less wear and tear and hence allows long continuous operating period.

A schematic of such a system is shown in fig.1. It basically consists of two major subsystems; a cryogenerator Module and a Compressor system. The compressor system provides continuous supply of oil-free helium gas to the cryogenerator module through two valves 'A' and 'B'. The cryogenerator module consists of a cylinder and a hollow displacer, which is filled with stacked Cu mesh. The displacer moves up and down inside the cylinder with the help of a motor. The load (cryotip) is placed at the top portion of the cylinder.

When displacer is at the top and valve A is open (valve B closed), high pressure helium gas enters through valve A and fills the cryogenerator. At this time the displacer is made to descend by the motor, with the valve A still kept open. The gas in volume 1 enters the volume 2 through the regenerator. Once the displacer reaches the lower end, the valve A closes and the valve B opens, thus connecting the cryogenerator module to the lower suction pressure of the compressor system. The gas within the cryogenerator does work to push out the gas that leaves during this process; therefore, energy is removed as work from the gas finally left in the expansion space (also called work in disguise). This causes the temperature of the lower pressure gas remaining in the expansion space (Volume 2) to drop to a

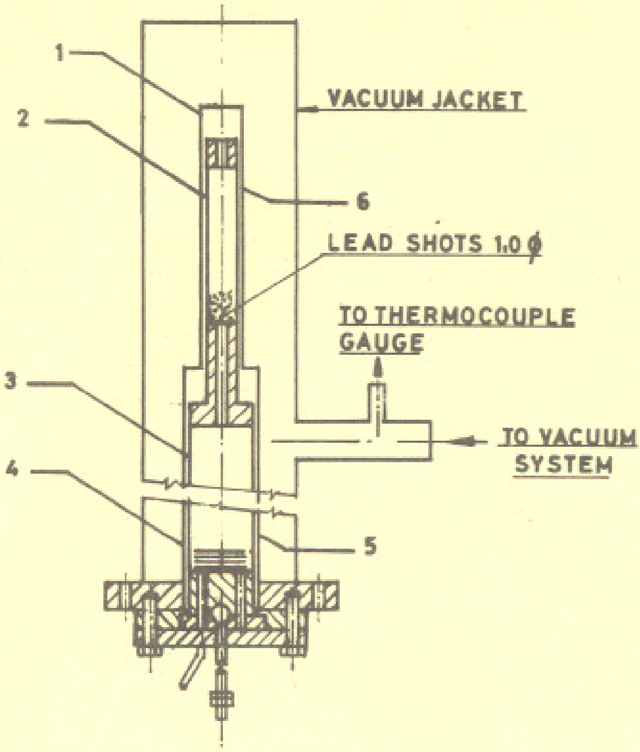

Fig.2. The two stage Gifford McMahon cycle cryorefrigerator developed at CAT. The numbers indicated in the fig. repersent- second stage cold tip (1); second stage displacer (2); first stage displacer (3); first stage regenerator (4); first stage cylinder (5); second stage cylinder (6).

lower temperature. Now the displacer starts moving up wards, forcing the gas in volume 2 to pass through regenerator. During this passage gas cools the regenerator. In the next cycle the cryogenerator is connected to A, and the displacer made to descend. The high pressure gas, therefore, passes through the regenerator to fill in volume 2 and gets cooled by the regenerator, which was cooled by the outgoing cooled gas in the previous cycle. Once the displacer reaches the lower end, valve A closes and valve B opens, cooling the gas further by expansion. Now the displacer starts moving upwards, forcing the cooled gas in volume 2 to pass through regenerator thereby cooling it, and the cycle repeats. In a single expansion stroke the temperature of gas drops only by about 8 degrees. This cools the regenerator and after repeated cycles a steady state is reached. In steady state if for example the machine is operating at 50 K, the gas cools from 300K to 50K in the regenerator itself and the temperature would further drop by 8 degrees due to expansion. Warming up of this cooled gas to the steady state temperature of 50K represents the actual refrigeration load. The regenerator should be designed to have very high efficiency (typically 99.7%). A small loss in regenerator efficiency results in a very high loss in refrigeration. With a single stage cryorefrigerator, temperatures down to 50K can be achieved (with load). A cascaded two stage system is required to obtain lower temperatures say down to 15K. The cryorefrigerator developed at CAT is a two stage system based on this Gifford McMahon cycle.

Cryogenerator module of the closed cycle cryorefrigerator developed at CAT is shown in fig.2. It consists of a stepped, thin walled, stainless steel cylinder and a stepped displacer made of perspex, moving inside the cylinder. The clearance between the cylinder and the displacer is not very critical and is between 0.075mm to 0.25mm. The displacer contains the first and second stage regenerators. The first stage regenerator is made of punched copper or phosphor bronze wire screens. Since the specific heat of copper falls very rapidly below 50K, lead balls are used in the second stage regenerator. Vacuum insulation is provided around the cryotip.

The compressor module should supply oil free, high pressure helium gas to the cryorefrigerator module. Because no compressor system for He-gas is available indigenously, a commercially available hermetic compressor used in airconditioning applications was used. These compressors are designed for Freon gas, which has a very low heat of compression. Since Helium has a much higher heat of compression, the use of these compressors would result in a very high exhaust gas temperature. This not only degrades the quality of the oil, but due to increased vapour pressure the oil can get carried over to the cryorefrigerator leading to temperature fluctuations. Therefore, additional cooling has to be provided for extracting this heat. The compressor was, therefore, modified by cutting it open and fixing cooling coils on inner and outer surface of the walls. To separate any oil carry over from the gas stream coming out of the compressor, an oil separator, charcoal and silica gel adsorbers are provided. However, this has not proved adequate. The exhaust gas temperature, inspite of the additional cooling provided, is about 130°C and therefore some compressor lubricating oil migrates over to the cryorefrigerator. This limits the continuous operation of the cryorefrigerator to 12 hours only, after which the temperature starts fluctuating. To overcome this problem we have further modified the compressor so that oil can be injected into the compressor during suction cycle. Addition of oil would increase the average specific heat of the oil-gas mixture, which will result in a smaller temperature rise. This oil mist is separated by passing the mixture through an oil bulk separator, and oil is returned to the compressor. The results from our preliminary experiments have been encouraging and suggest that with this method the exhaust gas temperature can be reduced to about 70°C. At this temperature the oil carry-over problem is reduced to a

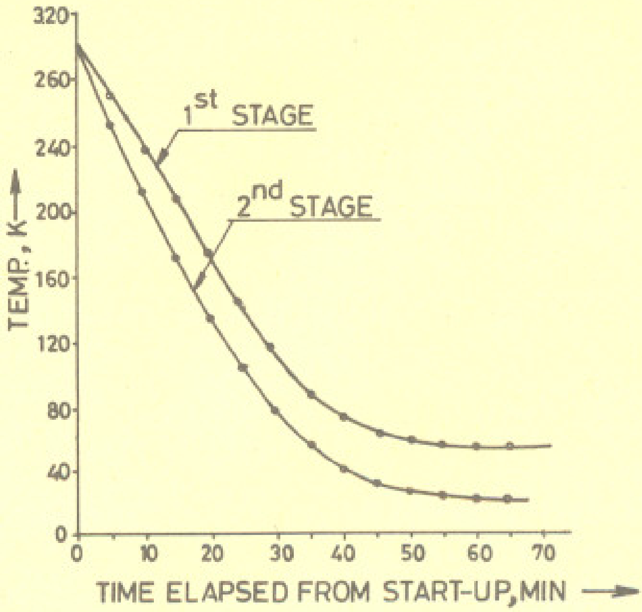

Fig.3. Cool down characteristics of the closed cycle cryorefrigerator.

considerably low level. This can be further reduced if a synthetic oil is used instead of a mineral oil, because the former has a very low vapour pressure at this temperature.

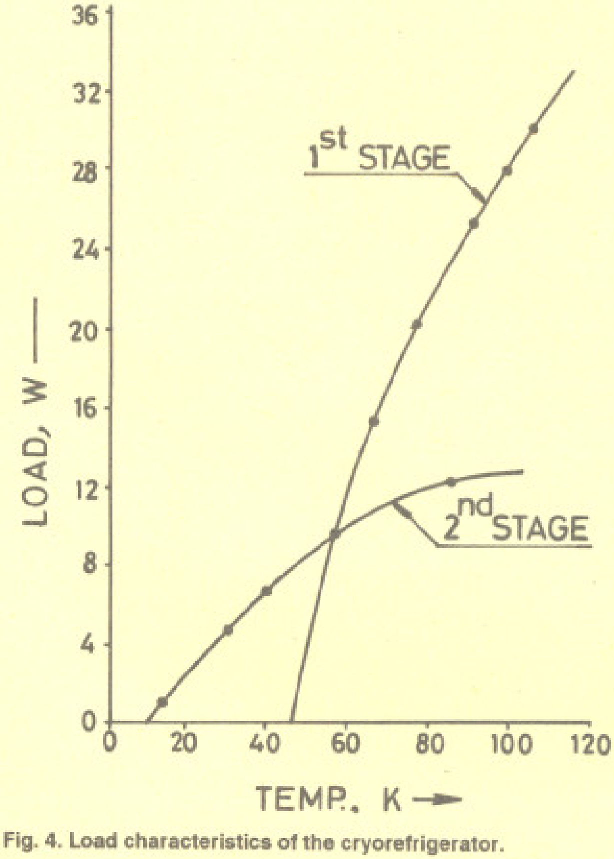

Fig. 4. Load characteristics of the cryorefrigerator.

The cryorefrigerator developed at CAT has a very simple flow reversing valve mechanism called "Spool Valve", whereas in other versions cams and follower, rotary valve etc. are used which are comparatively difficult to fabricate. This valve is actuated directly from the displacer rod through an actuator, which automatically sets the timing of opening and closing of valves in a proper sequence with the movement of displacer. It also provides a simple arrangement for adjustments.

The performance characteristics of the machine developed at CAT is shown in fig.4. The discharge and suction pressure were chosen to be 250 psi and 70 psi respectively for an optimum performance of the cycle. This machine reaches a temperature of 20K in about 60 minutes from start up, as shown in fig.3. Refrigeration load that can be handled at 20K is about 2.5 W (fig.4).

This cryorefrigerator has also been converted to a cryopump by putting baffle and cryopanel as heat load on the cryotip. Detailed characterisation of the cryopump is in progress. Work is also being carried out to achieve 10K with 1 W heat load. For this the two stage cryorefrigerator will be cascaded into a three stage machine. This system when developed can be used to make a small laboratory type Helium liquefier/ refrigerator. This refrigerator will be able to extend the temperature range for experiments right down to the boiling point of Helium (4.2K, at atmospheric pressure). In this case, a separate stream of high pressure Helium gas will be precooled successively at three stages of the G-M cycle cryorefrigerator, in combination with a series of counterflow heat exchangers, and then throttled through a Joule Thomson valve to produce liquid Helium. This system is expected to produce 0.5 to 1 l/h of liquid Helium.

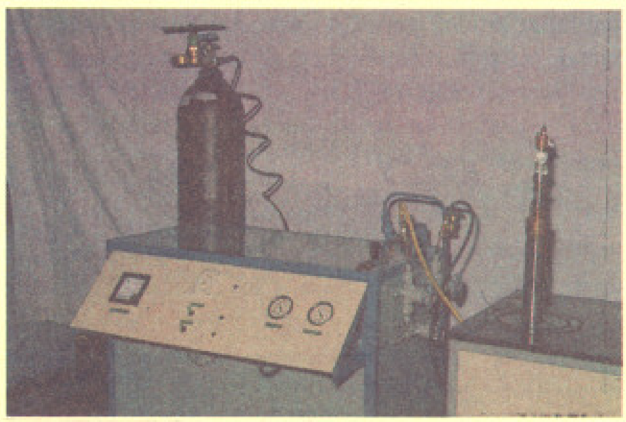

Fig.6. Closed cycle Helium cryorefrigerator developed at CAT. On left is the compressor module and on right is the cryogenerator (cold tip, without vacuum jacket).

P K Kush