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Thesis title:

Studies on single and two stage Stirling type pulse tube coolers of low and medium capacities including performance enhancement of pressure wave generator and a novel helium recondensation system

Abstract:

Cryocoolers are mechanical devices that produce cold at temperatures below -150^{o}C. Work required to produce the cold is supplied by a Pressure Wave Generator (PWG). This thesis is concerned with the development and analysis of Stirling type pulse tube cooler (PTC) systems of low and medium capacities along with performance improvement of PWG and design of a novel oil free and low maintenance helium recondensation system based on Stirling type pulse tube coolers and Joule-Thomson expansion.

Pressure Wave Generator is a crucial part of pulse tube cooler system. Performance of PWG depends on many parameters like the seal gap, piston diameter etc. Effects of these parameters have been studied in detail. Analysis was done to arrive at optimal values and a methodology is suggested to improve performance. The analysis was applied extensively to indigenously developed Pressure Wave Generator (PWG-1). A significant improvement, reduced mechanical losses and lowered input electric current, has been found by application of the suggested methodology.

The development of pulse tube coolers of low and medium capacities was studied. In low capacity coolers, the available PV power is low; thus, requiring an ultra efficient design. In medium capacity coolers, the available PV power can pose problems like acoustic matching, streaming etc.

A low capacity pulse tube cryocooler capable of 0.5 W at 80 K and acoustically matched to indigenous Pressure Wave Generator PWG-1 was designed, fabricated and tested. Inertance tube configuration which plays significant role in low input power coolers has been analyzed. A no load temperature of 74 K was achieved with input power of 59 W; corresponding to a cooling power of 0.22 W at 80 K. The amplitude of mass flow

passing into the pulse tube cooler has been measured by using a hot wire anemometer calibrated in oscillatory flow condition.

A medium capacity pulse tube cryocooler capable of 10 W at 80 K was designed and developed. It requires an estimated input PV power of 375 W. On the other hand, the only available large PWG for this work, PWG-2, has a rated PV power output of 900 W at the rated piston stroke, thus posing the problem of acoustic matching. Improvement of acoustic matching between the PTC and PWG was studied by varying filling pressure, inertance tube configuration, and by using a long transfer line. A no load temperature of 72 K corresponding to 1 W at 80 K was achieved. It is concluded that steps to improve acoustic matching are useful only to a limited extent and acoustic matching has to be ensured at the design stage itself.

A medium capacity two stage pulse tube cooler capable of reaching 25 K is described. Analytical proof has been given to shown that a two stage pulse tube cooler is thermodynamically less efficient than a single stage pulse tube cooler. But a two stage PTC is required to reduce regenerator losses. A no load temperature of 40.4 K was achieved at 24.1 bar filling pressure with an input power of 750 W. The effects of pulse tube volume and regenerator configuration were experimentally investigated. The results point out the interplay of pressure drop and regenerator ineffectiveness losses. It is concluded that high mass flow from the PWG-2 is the reason for ineffectiveness of regenerator. A twin cooler design to reduce the mass flow of PWG-2 reaching the coldest stage has been proposed.

A novel oil free and low maintenance helium recondensation system has been designed with a liquefaction rate of 17.86 liters per day corresponding to a cooling power of 0.53 W at 4.2 K. The system reaches liquid helium temperature by precooling helium gas in tube-in-tube heat exchangers, assisted by Stirling type pulse tube coolers operating at 80 / 25 K and two stage JT expansion. The cooling powers required of the pulse tube coolers are 14.22 at 80 K and 1.6 W at 25 K respectively. The twin cooler is capable of meeting these cooling power requirements. Design and development of tube-in-tube heat exchangers and JT valves are discussed.