Abstract

Cryocoolers, which operate in a closed cycle with helium as the working fluid, produce refrigeration at cryogenic temperatures, i.e. temperatures below 123 K ($-150^{\circ}C$). Refrigeration at such low temperatures is needed in the fields of electronics, space communication, defence, medicine, production of high vacuum, high energy physics etc. There are several types of cryocoolers, employing thermodynamic cycles such as modified Solvay, Gifford-McMahon, reverse Stirling and Vuilleumier. All these cycles are slight variations of each other and a common factor in them is the use of a highly effective regenerator. The choice of one cycle over another depends on many factors like cost, weight, volume, vibration, reliability, efficiency etc. of the machine and the emphasis on any one of them depends on the application of the machine.

Cryorefrigerators working on Gifford-McMahon (G-M) cycle have been very widely used in ground applications, due to their low cost, simplicity of construction and high reliability of operation. These cryorefrigerators, invented by Gifford and McMahon in 1960, have a long maintenance-free life with Mean Time Between Failures (MTBF) of the order of 6000 - 10000 hours. Although the coefficient of performance (COP) of G-M cryorefrigerators is very low compared to that of other machines, for example reverse Stirling, it has been preferred in applications, where reliability is often the decisive factor. This results from the low speed of the displacer in G-M machines, which results in less wear of the seal. The major application of cryorefrigerator is in cooling cryopump panels, which are widely used in semiconductor industries and space simulation.

There have been various models of G-M cryorefrigerators made by many companies the world over. They are mostly of two-stage design, although single stage refrigerators are also available. Their refrigeration power at a particular cooling temperature varies widely and along with that vary the cold head and

compressor sizes and their costs. The capacity of two stage G-M cryocoolers range from few watts to a few tens of watts. While the smaller units are used in scientific experiments, the larger ones are used for cooling cryopump panels. A single stage G-M cryocooler may be used to build a small scale nitrogen liquefier.

The estimation of the performance of a G-M machine is a complex task. The performance of a G-M machine is determined from the estimation of its gross and net cooling capacities. The gross cooling capacity is given by the P-V work in the expansion chamber. The P-V work is directly coupled with the displacer dynamics, valve timing and other geometric and operating parameters. The method adopted here to find the P-V work couples the thermodynamic and fluid dynamic equations to the equation that governs the motion of the displacer. The net cooling capacity is determined from the computation of various loss mechanisms such as regenerator ineffectiveness loss, shuttle heat transfer loss, axial heat conduction loss through cylinder, displacer and regenerator matrix, and radiation loss through the vacuum insulation.

It has been concluded from the review of literatures that, at present, there is no established methodology for design of a Gifford - McMahon cryorefrigerator with a given heat load .vs. temperature characteristic. Various authors have analysed the ideal performance of G-M machines based on geometric and operating parameters The estimation of various losses occurring in the real machine are also available in the literature. It is the purpose of the present research to combine the existing information in the open literature and establish a coherent design criterion which will help design a G-M machine of specified capacity.

A simulator, named 'GMAC' has been developed to estimate the performance of G-M machines of given geometric and operating parameters. The validity of the simulator has also been checked by performing experiments using a commercially available G-M cryocooler (Model RG20, M/s Leybold AG, Germany). The simulator has been used to study the effect of hardware modifications on the performance of any G-M cryocooler. Using the simulator, designs for two single stage cryocooler models ranging from 5 watts at 80 K to 200 watts at 60 K have been presented.