Development of a Diaphragm Stirling Cryocooler

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ABSTRACT

Callaghan Innovation, formerly Industrial Research Ltd, has developed a novel free-piston Stirling cryocooler concept using metal diaphragms. The concept uses a pair of metal diaphragms to seal and suspend the displacer of a free-piston Stirling cryocooler. The diaphragms allow the displacer to move without rubbing or moving seals, thus resulting in a long-life mechanism. When coupled to a metal diaphragm pressure wave generator, the system produces a complete Stirling cryocooler with no rubbing parts in the working gas space. Initial modeling of this concept using the Sage modelling tool indicates the potential for a useful cryocooler. A proof-of-concept prototype was constructed and achieved cryogenic temperatures. CFD modeling of the heat transfer in the radial flow fields created by the diaphragms shows the possibility of utilizing the flat geometry for heat transfer, reducing the need for, and the size of, expensive heat exchangers.

A second prototype has been designed and constructed using the experience gained from the first. Further CFD modeling has been used to understand the underlying fluid-dynamic and heat transfer mechanisms and refine the Sage[1] model. The prototype produces 29 W of cooling at 77 K and reaches a no-load temperature of 56 K. This paper presents details of the development, modeling and testing of the second prototype.

INTRODUCTION

Callaghan Innovation has developed a novel metal diaphragm-based pressure wave generator technology[2–4] that has been successfully used with pulse tube refrigerators [5–8]. To date, 15 metal diaphragm pressure wave generators have been made and operated with swept volumes from 20 cc to 1000 cc and with 500 W to 30 kW input power, respectively. The diaphragm concept uses a pair of opposed metal diaphragms to balance each other's average gas forces, transferring only the forces from the pressure oscillation to the driving mechanism.

The concept discussed in this paper is illustrated in Figure 1. It uses a pair of metal diaphragms to suspend the displacer of a free-piston Stirling cryocooler. The regenerator is housed within the displacer and an intermediate membrane separates the equivalent of the traditional bounce space[9] from the main pressure wave. Early Sage modeling was very promising and a proof-of-concept prototype was constructed[10]. The proof-of-concept prototype demonstrated cooling at cryogenic temperatures, but did not perform as well as initially

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