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Research Paper

The performance test of a modified miniature rotary compressor in upright and inverted modes subjected to microgravity

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HIGHLIGHTS

- A miniature rotary compressor by ASPEN company was modified.
- The modified compressor can be employed in microgravity.
- Performance of upright compressor is superior to inverted mode in most cases.
- Performance curves of system with inverted compressor are obtained.
- Experimental results of compressor inverted and upright are compared.

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ABSTRACT

Vapor compression heat pump is a new concept of thermal control system and refrigerator for future space use. Compressor is a key component in the vapor compression heat pump. Development of compressor capable of operating in both microgravity (10 E-6 g) and lunar (1/6 g) environments is urgently needed for space thermal control systems based on heat pump technique. In this paper, a miniature rotary compressor by ASPEN company was modified to realize acceptable compressor lubrication and oil circulation in microgravity environments. An experimental system was built up to check the performance of the modified compressor subjected to microgravity. A performances comparison of inverted compressor with upright one was made. The influences of operating parameters such as refrigerant charge, cooling water temperature as well as compressor speed on the performances of vapor compression heat pump were investigated. The results show that the modified miniature rotary compressor in inverted mode can operate stably in a long period, which indicates that the modified compressor can be employed in microgravity environments. Compressor discharge temperature increased or decreased while COP changed more obviously with cooling water temperature and speed in microgravity. In most cases, performance of the upright compressor is superior to that of the inverted one. But when the compressor speed is from 1500 rpm to 2500 rpm or the coolant temperature is between 20 and 25 degrees, the performance of inverted compressor is better. The highest discharge temperature of the inverted compressor can be as high as 1.7 times that of the upright one. The maximum of heating COP and cooling COP of upright compressor is respectively 1.21 and 1.16 times that of inverted compressor. The study of modified miniature rotary compressor on gravity-independence provides an experimental basis and lays foundation for space applications.

1. Introduction

We face a greater challenge of extreme temperatures than on Earth when exploring space. The surface temperature fluctuation is large, but the internal members and precision equipment need a suitable temperature environment. Therefore, future space explorers will likely turn to mechanical heating and cooling systems to maintain comfortable living spaces. Earlier studies have shown that vapor compression cycle heat pumps are the most mass and power efficient for space applications [1]. A heat pump is a device that elevates the temperature of a heat flow by means of an energy input, thereby the heat pump can cause heat to transfer from a cool region to a warm one. This approach has been adopted in many common devices such as refrigerators or air conditioners. For

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aerospace applications, vapor compression heat pump can be used as thermal control system to collect the heat from electronic devices and transport the heat to radiator, whereby the heat can be rejected to space. Heat pumps can be used in two ways. In the first way, the temperature of heat source is raised so that the surface area of radiator can be reduced. The second is employed in those situations where the heat cannot be directly rejected by radiators, because the heat sink temperature is higher than that of the heat source. One example is a lunar base habitat near the moon's equator. The surface temperature peaks at about 390 K during the 336-h lunar day. Other situations include lunar rovers that have long life expectancy, a Mars lander with high heat flux dissipation and other spacecrafts to operate in very low Earth orbits, all of them operate in a higher thermal sink environment. The direct dissipation of waste heat from the lunar base would be impractical, which would result in an adverse temperature gradient. A vapor compression augmented thermal control system can be used to increase the operating temperature of the radiator, thereby enabling heat rejection.

Many researches focused on heat pump design and optimization in which, however, people commonly assume that vapor compression heat pump is efficient and suitable for space stations. However, as mentioned in the published literature [2], design of heat pumps for aerospace and low-gravity applications is relative paucity. In 1977, Emmen and Savage [3] proposed vapor compression heat pump as a refrigeration equipment on the space to provide low-temperature environment needed for some important missions. In 1984, Dexter and Haskin [4] analyzed the advantages of vapor compression heat pump as a spacecraft thermal control system and found it superior to other solutions from quality optimization. Searinge et al. [5,6] et al. analyzed vapor compression heat pump applications in spacecraft thermal management systems and proposed the idea of matching energy system to optimize heat distribution throughout the spacecraft. Woolley patented an oil separator claimed ideally suited for application in zero-gravity environments [7]. NASA has studied vapor compression systems employed in the aerospace field since mid-1980s. NASA not only assessed relevant theories and specifications of gravity-insensitive heat pumps but also did detailed analysis of technical barriers in microgravity conditions and planned for future missions [3,8,9]. In China, Li et al. analyzed the effects of various parameters on the quality and temperature of photovoltaic (PV) vapor compression heat pumps and demonstrated the great potential of heat pumps in future space applications [10]. Scaringe et al. proposed an attractive design choice for future manned thermal control applications: the use of a heat pump to reject heat to space, the use of non-toxic thermally stable working fluids, and the use of high-performance lubrication-free (gravity independent) refrigeration compressors [11]. Domitrovic et al. developed a highly efficient recuperative vapor compression heat pump and tested its ability to operate independent of orientation with respect to gravity while maximizing temperature lift to optimize size [12]. Cole described preliminary work on a development project for a 5 kW–15 kW cooling capacity heat pump that would achieve a COP of 1.7 with evaporation and condensation temperatures of 4.44 °C and 60 °C, respectively [13]. Park proposed a complex hybrid two-phase thermal control system which was vapor compression system combined with capillary [30]. Chen et al. tests the gravity independence of compressor performance, and evaluates the performance of compressor and heat pump system in micro-gravity environment. They tested the performance of the compressor at different tilt angles from 0° to 60° and obtained the influence law of tilt angle on the compressor performance [14]. Bella and Lemorta optimized vapor compression heat pumps for satellite cooling. They used an oil-free scroll compressor in place of the oil-lubricated compressor and considered R152a as ideal working fluid [2].

In addition, a significant advantage of utilizing forced convection heat transfer for spacecraft thermal management applications is that high heat fluxes are yielded that allow exchange equipment to be substantially compacted and reduced in mass [15]. Therefore, there are some design and optimization on forced convection of space heat exchanger. Heat sink is a cold plate close to the heat source collecting heat by conduction and convection. It is found that there exists an optimal thickness for the plate that minimizes the highest temperature in the heat source. The optimum plate thickness and the associated minimized temperature are found to be dependent on the Reynolds number and the solid-to-fluid thermal conductivity ratio [16–19]. The optimization of heat transfer/fluid flow can be done by exploring the optimal distribution of heat flux [20–22]. Space heat exchanger is optimized by choosing optimal architecture (width, location and cross section area), heaters size and heat generation rates regarding the application and the total annual cost of the system [23–29].

Compressor is a key component in the vapor compression heat pump system. Terrestrial heat pump compressors rely on gravity for proper oil circulation in bearings, seals, and other contact surfaces, as well as proper refrigerant/oil management in two-phase heat exchangers. However, oil separation from refrigerant is very difficult in microgravity environment. It was in urgent need to develop special lubrication and oil circulation technology for compressors working in microgravity environment.

Aspen Thermal Company developed a miniature rotary compressor whose maximum cooling capacity reached 500 W. It has been widely used in refrigeration of electronics, communications and military except aerospace. But so far nobody has performed any experiment on its adaptability to the microgravity in space. Parabolic flight and drop tower experiment will continue in microgravity for a short time, and experimental space has many limitations. Therefore, a new approach and methods have been proposed. It is generally recognized that a compressor can be used in microgravity environments if the compressor can operate stably in a long period when the compressor is inverted. So it is very important to study the performance of compressors working in inverted mode.

The main objective of this paper is to find an appropriate modification to achieve proper oil lubrication and circulation for the miniature rotary compressor in microgravity environments, investigate the influence of operating parameters on the performances of vapor compression heat pump and compare the performances of inverted compressors with upright ones.

2. Modification of a miniature rotary compressor

The miniature rotary compressor of Aspen Company was chosen for experiments because of its small size, lightweight, low power consumption, small vibration and precise control. The hermetically-sealed miniature rotary compressor operates with a rolling piston mechanism and uses a brushless electric motor that runs on a 24 V DC power supply. The compressor is the smallest and lightest compressor ever developed for refrigeration systems. Fig. 1 shows the important external dimensions of the compressor, while its specifications are given in Table 1. Speed was controlled by a voltage adjusting drive module. The compressor can produce 500 W of cooling capacity at 38 °C environment. It has been widely used for refrigeration in electronics, communications and military except aerospace. But so far nobody has performed any experiment on its adaptability to microgravity in space. The schematic and detailed structure of the compressor is showed in Fig. 2 and Fig. 3, respectively. The lubricants path of compressor upright and inverted is displayed in Figs. 4 and 5, respectively. The gas exiting from the evaporator is back into the cylinder through the gas-liquid separator under normal gravity. After being compressed the gas flows through the exhaust valve into the muffler. After cooling the motor around, the