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Study on Gravity Independence of Compressor Performance for Space-borne Vapor Compression Heat Pump

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ABSTRACT

Vapor compression heat pump is an important aerospace thermal control means to lunar probe program and deep space exploration. Compressors are the most important component in vapor compression heat pump systems. Micro-gravity environment has a great impact on system performance. The paper tests the gravity independence of compressor performance, and evaluates the performance of compressor and heat pump system in micro-gravity environment. The results show that the maximum tilt angle is about 60° under the condition of low speed operation. The inclination angle of compressor has little effect on evaporation and condensation pressure. Evaporation and condensation pressure is 4.3 bar and 12 bar, respectively, and the pressure ratio is mainly steady. When the compressor works at full speed, the maximum tilt angle is 20°. Under the condition that the tilt angel is less than 20°, the performance parameters do not change with the increase of the inclination angle. Evaporation and condensation pressure stabilize at 4.2 and 13 bar, respectively. Energy efficiency ratio and coefficient of performance are about 2.7 and 3.6, respectively.

1. INTRODUCTION

Aerospace technology plays an important role in the modern scientific research and engineering applications. Most energy consumed by equipment inside the spacecraft will be converted into waste heat. With the extensions of the functions and scales of large spacecraft, the power will increase gradually. How to improve the ability of heat radiation is the current important issue which needs to be resolved.

Berner and Savage (1981) began to study vapor compression heat pump used in space missions in 1977. They put forward a vapor compression heat pump as single refrigeration equipment on the space station to provide required low-temperature environment for some important items. Dexter and Haskin (1984) analyzed the superiority of vapor compression heat pump as a spacecraft thermal control system compared with other schemes, from the view of the optimization of thermal control system. Hanford and Ewert (1996) evaluated the application prospects of a variety of new thermal control technology for future space missions.

Compressors are the most important component in vapor compression heat pump systems. How to improve the performance of aerospace refrigeration compressors is a key technology. For space-borne heat pump systems, micro-gravity environment has a great impact on system performance, mainly in compressor lubrication, heat transfer, etc. Scaringe *et al.* (1989) analyzed the application prospects of vapor compression heat pump in spacecraft thermal management system. They proposed an idea of energy matching in systems: when the cooling load is low, small displacement compressors without lubrication should be used in heat pump system under the condition of micro-gravity; when the thermal load is high, magnetic bearing centrifugal compressors with low vibration, compactness, and durability are used. George · Marshall Space Flight Center (1993) carried out a research for heat storage systems in space station and refrigeration systems during 1985-1993. They developed vapor compression refrigeration equipment under micro-gravity condition. The project used improved diaphragm compressors to avoid the contact between oil and refrigerant vapor.

Aspen Compressor Company in USA had developed a smallest and lightest miniature rotary compressor ever developed for refrigeration system. However, it is necessary to verify the compressor availability in microgravity environments. The main task of this paper is to carry out the performance test for the compressor at different tilt angles and obtain the influence law of tilt angle on the compressor performance.

2. METHODS

2.1 Compressor Performance Text System

The test system of compressor performance mainly consists of three parts: refrigerant cycle system, water cycle system and data acquisition system (Figure 1).

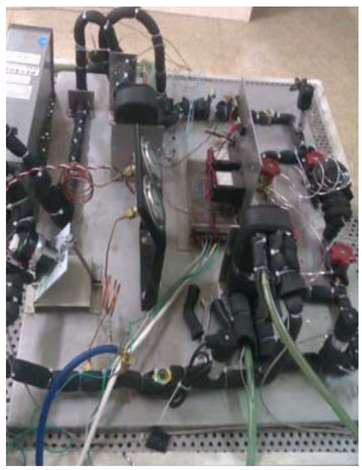

Figure 1: Experimental design of the test system for compressor performance

Refrigerant cycle system is the core part of the experiment system, including four parts: a compressor, a plate condenser, thermostatic expansion valve and a plate evaporator. The refrigerant used in the experiment is R134a.

Water cycle system comprises two small systems: cooling water cycle system (at condenser side) and chilled water cycle system (at evaporator side). Each water system includes constant temperature water bath, flow meter, circulating pump, flow switches and other components. Chilled and cooling water mass flow can be changed by adjusting switches.

Data acquisition system includes thermal resistor, pressure gauge, data acquisition instrument, ammeter, voltmeter and other components. Collecting data mainly includes temperature, pressure and water mass flow.

The tested compressor is manufactured by Aspen Company in USA. The compressor is the smallest and lightest compressor ever developed for refrigeration system. The compressor is designed for connection to 12/24V DC power supply and primary use with refrigerant R134a. The hermetic compressor is driven by brushless motor with advanced motor drive controller, which allows variable speed for load following, high efficiency and precise temperature control. Table 1 shows the relevant parameters of the compressor.

In order to tilt the compressor at different angles, a base connected with plate is used. The inclination angle of compressor can be changed by adjusting the angle of plate (Figure 2).

Table 1: Technical parameters of rotary compressor

Weight	**Size**	**Motor**	**Voltage**	**Electric current**
630g	Φ56×72mm	Brushless direct-current (DC) motor	DC 20-30V	1.0-9.5A
Speed	**Refrigerant**	**Evaporation temperature**	**Condensation temperature**	**Highest exhaust temperature**
1800-6500rpm	R134a	-18-24°C	27-71°C	130°C
Highest compression ratio	**Compressor adjustment method**			
8	Governor			

Figure 2: Compressor performance test bench

2.2 Data processing

Main performance index of test system are cooling capacity, heat release, power, energy efficiency ratio (EER) and coefficient of performance (COP), which are calculated according to corresponding enthalpy. Enthalpy can be obtained with pressure and temperature in the experiment.

① Cooling capacity

Cooling capacity represents the heat absorbed by refrigerant from environment in the evaporator. Unit cooling capacity can be calculated by refrigerant specific enthalpy difference at the inlet and outlet of evaporator.

$$Q_0 = M \cdot q_0 = M \cdot (h_{\mathrm{evo}} - h_{\mathrm{evi}}) \tag{1}$$

where Q_0 is cooling capacity; M is refrigerant mass flow; q_0 is unit cooling capacity; h_{evi} and h_{evo} are specific enthalpy at the inlet and outlet of evaporator, respectively.

② Heat release

Heat release is the heat release by refrigerant to environment in the condenser. Unit heat release can be calculated by refrigerant specific enthalpy difference at the inlet and outlet of condenser.

$$Q_{\mathrm{k}} = M \cdot q_{\mathrm{k}} = M \cdot (h_{\mathrm{cni}} - h_{\mathrm{cno}}) \tag{2}$$

where Q_{k} is heat release; q_{k} is unit heat release; h_{cni} and h_{cno} are specific enthalpy at the inlet and outlet of condenser, respectively.

③ Power

Power means the work consumed by refrigerant compression and transportation. Since there's no power consumed during throttling process, the cycle power equals to compression power. Unit power can be calculated by refrigerant specific enthalpy difference at the inlet and outlet of compressor. The power is not only related to refrigerant characteristics, but also related to compression ratio.

$$W_0 = M \cdot w_0 = M \cdot (h_{\mathrm{cpo}} - h_{\mathrm{cpi}}) \tag{3}$$

where W_0 is power; w_0 is unit power; h_{cpi} and h_{cpo} are specific enthalpy at the inlet and outlet of compressor, respectively.

④ EER

EER is the ratio of cooling capacity and power.

$$\mathrm{EER} = \frac{Q_0}{W_0} \tag{4}$$

⑤ COP

COP is the ratio of heat release and power.

$$\mathrm{COP} = \frac{Q_{\mathrm{k}}}{W_0} \tag{5}$$

3. RESULTS AND DISCUSSION

3.1 Compressor performance at low rotating speed

The compressor is under low speed operation. Experimental conditions are listed in Table 2. Figure 3 shows the changes of evaporation and condensation pressure, when the compressor tilt angle increases from 0° to 60°. The inclination angle of compressor has little effect on evaporation and condensation pressure under the condition of low speed operation. The evaporation and condensation pressure is 4.3 bar and 12 bar, respectively. The pressure ratio is mainly steady. Figure 4 shows the curves of corresponding evaporation and condensation temperature as the inclination angle of compressor increases. Both the values of evaporation and condensation temperature do not change significantly.

Table 2: Experimental conditions of low speed operation of compressor

Inlet temperature of chilled water (°C)	Mass flow of chilled water (kg/h)	Inlet temperature of cooling water (°C)	Mass flow of cooling water (kg/h)	Refrigerant charge quantity (g)
13±0.1	119.34	29±0.1	89.82	230

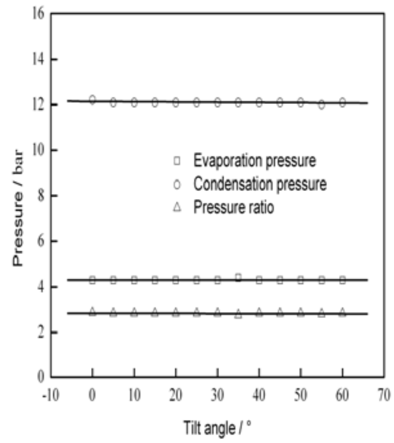

Figure 3: Evaporation and condensation pressures under different tilt angles of low speed operation of compressor

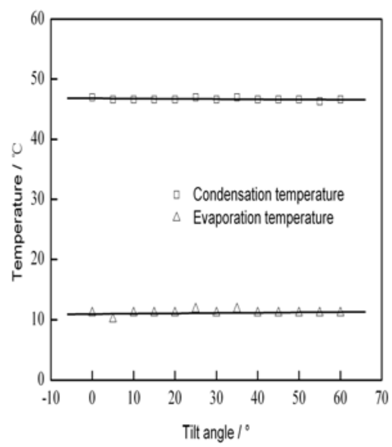

Figure 4: Evaporation and condensation temperatures under different tilt angles of low speed operation of compressor

The changes of cooling capacity, heat dissipating capacity and power consumption of different tilt angles under the low speed operation are shown in Figure 5. Compressor tilt angle has little effect on cooling capacity, heat dissipating capacity and power consumption. The power consumption is about 66W. The cooling capacity and heat dissipating capacity are 280W and 220W, respectively. The EER is about 3.3, and COP is about 4.2, which has little change as the increase of tilt angle (Figure 6).

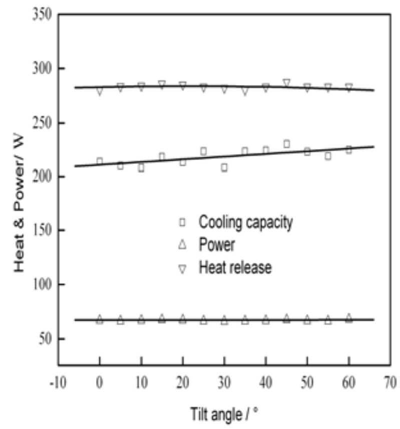

Figure 5: Cooling capacity, heat dissipating capacity and power consumption under different tilt angles of low speed operation of compressor

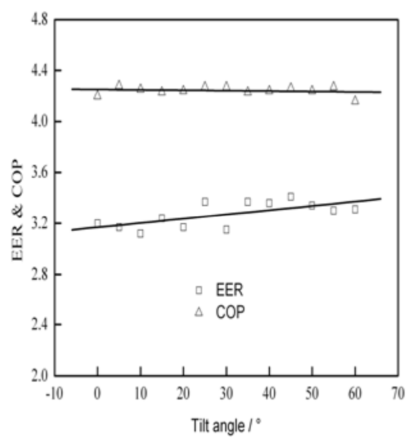

Figure 6: EER and COP under different tilt angles of low speed operation of compressor

3.2 Compressor performance at full rotating speed

The compressor works in full. Experimental conditions are shown in Table 1. When the tilt angle ≤20°, the compressor is under normal operation. The discharge temperature and other parameters stabilize within about half an hour. When the tilt angle≥20, the compressor still run. The discharge temperature goes up continuously. There follows that the compressor can not continue to maintain the operation, resulting in downtime. When the compressor works at full speed, under the conditions of tilt angle of 10°, 15° and 20°, the system performance is shown in Figure 7-10.

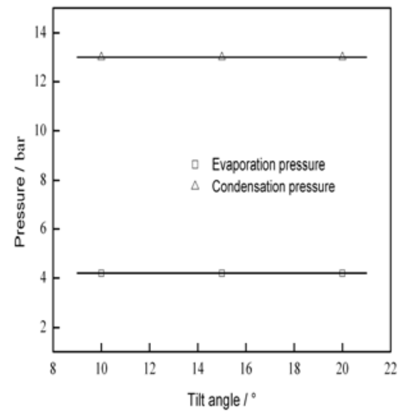

Figure 7: Effect of tilt angle on evaporation and condensation pressure under the condition of compressor working at full speed

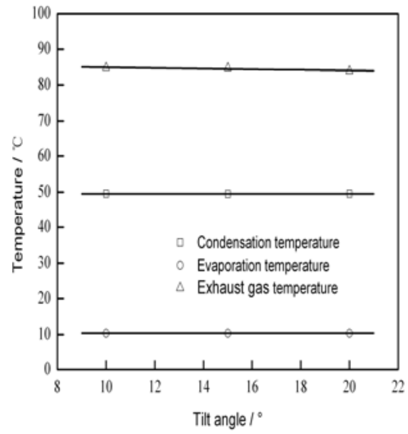

Figure 8: Effect of tilt angle on evaporation and condensation temperature under the condition of compressor working at full speed

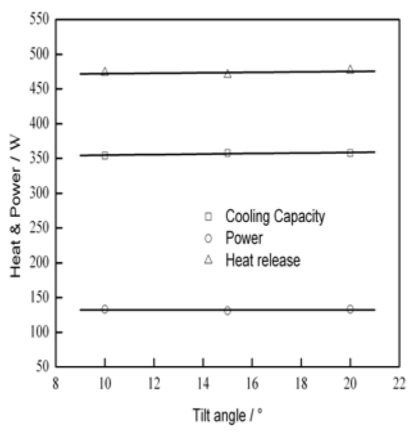

Figure 9: Effect of tilt angle on cooling capacity, power and exhaust heat under the condition of compressor working at full speed

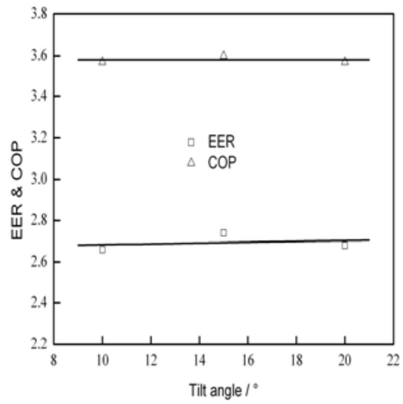

Figure 10: Effect of tilt angle on EER and COP under the condition of compressor working at full speed

The results show that when the compressor works at full speed (control voltage of 5V), the maximum tilt angle is 20°. Under the condition that the tilt angle is less than 20°, the performance parameters (including evaporation temperature, condensation temperature, compressor discharge temperature, cooling capacity, power and so on) do not change with the increase of the inclination angle. Evaporation and condensation pressure stabilize at 4.2 and 13 bar, respectively. Evaporation and condensation temperature stabilize at 10.39 and 50℃, respectively. Cooling capacity is 358W, and exhaust heat is 475W. EER and COP are about 2.7 and 3.6, respectively.

4. CONCLUSIONS

The paper studied the independent of gravity performance of Aspen rolling rotor compressor, based on the reform of existing micro-compressor heat pump system. The conclusions are as follows:

When the compressor is under low speed operation, the inclination angle has little effect on evaporation and condensation pressure, evaporation and condensation temperature, cooling capacity, heat release, power consumption. EER and COP are about 3.3 and 4.2, respectively.

When the compressor works in full, the maximum tilt angle is 20°. Under the condition that the tilt angel is less than 20°, the performance parameters do not change with the increase of the inclination angle. EER and COP are about 2.7 and 3.6, respectively.

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