Operation Performance Test of Aerospace Mechanical Pumps and Verification of Their Environmental Adaptation

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Abstract. In this paper, one aerospace centrifugal pump with flowrates of 1~2g/s was developed which was applicable to the mechanically pumped two phase loop (MPTL) system. Moreover, an experimental test platform was built to test and verify the performances of pump. Besides, the environmental adaptation tests of the designed pump were verified. Results show that: 1) the flow rate and lift of the pump at the rated working point are 2.043g/s and 0.0517MPa, while the input power is only 9.92W. These can meet requirements of the design indexes. 2) The input power is only 4.71W under the two-phase operation state and this pump can transfer the heat of 240W, and the pump shows a very high energy efficiency ratio (EER). 3) The lift of designed pump is constant at specified rotation speed and it can assure the temperature stability of MPTL system. 4) This pump can meet the requirements of services in vibration, vacuum and thermal cycling environments.

1. Introduction
Recently, remote-sensing technology is developing toward large diameter and high resolution[1-2]. It proposes increasingly strict requirements on heat control. As a active thermal control technique, MPTL possesses the characteristics of high heat dissipation capability, long transmission distance and small driving power consumption. It is one of effective means to solve thermal control difficulties of large-diameter remote sensor in spaces[3-4].

The structure of MPTL system is shown in Fig.1. It is composed of a mechanical pump, a reservoir, a heat exchanger, a preheater, several cold plates, connecting pipelines and a condenser. The mechanical pump is the driving force of the system, while the reservoir is the temperature-controlling unit of the system. This system acquires heat from the heat source by the latent heat of phase change of working media.
Mechanical pump, one of core components of the technology, is the “heart” of this system and it provides power for the operation of the system. The system may not operate normally when there’s a failure of mechanical pump. According to investigation, there are few pump products applicable to MPTL system. Technicians in this field mainly have studied the technology by using the gear pump of micropump[5-6]. Gear pump has many disadvantages. Firstly, it has a short service life. Secondly, the working point of the pump changes when the two-phase running state is changed and flow resistance and flow rate of the system are altered. Thirdly, lift and flow rate of the pump are changed simultaneously, thus causing temperature shift at the two-phase temperature controlling point and thereby influencing the applications of the two-phase technology. To meet applications in the aerospace remote sensing field, an aerospace mechanical pump which is applicable to MPTL system was developed in this study.

2. Introduction to the aerospace mechanical pump

Technological parameters of the mechanical pump are listed in Table 1. The mechanical pump uses the design scheme of shielding centrifugal pump. The physical picture of this pump is shown in Fig.2. The designed flow rate and lift of the pump are 1~2 g/s and 0.02~0.05 MPa, respectively. NH3 is an appropriate working media and the designed rated rotating speed is 11,000 rpm. The input power at the specified working point was 10 W and the designed service life was 8 years. The pump realized zero leakage by a distance sleeve. It is applicable to the occasions where having high requirements on the leakage and no long-term maintenance.

Table 1 Design indexes of the mechanical pump

| Parameters                  | Requirements | Notes |
|-----------------------------|--------------|-------|
| Working media               | NH3          |       |
| Density                     | 615 kg/m3    |       |
| Flow rate                   | 1~2 g/s      |       |
| Lift                        | 0.02~0.05 MPa|       |
| Maximum speed               | 11000 rpm    |       |
| Net positive suction head   | 0.2 MPa      |       |
### Table 1

| Parameter                                    | Value          |
|----------------------------------------------|----------------|
| Designed service life                        | 8 years        |
| Input power                                  | 10 W           |
| Acceleration of sinusoidal vibration         | 8 g, 10~100 Hz |
| Acceleration of random root-mean-square      | 8.1 grms, 10~2000 Hz |
| Thermal vacuum testing conditions            | -25~+60 °C, ≥3 cycles |
| Thermal temperature circulation testing conditions | -25~+60 °C, ≥12 cycles |
| Working media                                | NH3            |

**Fig.2 Physical picture of aerospace mechanical pump**

3. **Test platform**

The setup of MPTL system in Fig.3 was built. It is composed of a mechanical pump, a reservoir, a filter, a heat exchanger, a flowmeter, several evaporators, and pipelines (clean and burr-free). Functions and technological parameters of different components are shown in Table 2. During the operation process of the system, the pump operates to provide powers and drive working media flow to the evaporator to absorb heat. Temperature increases to the saturation value and then the working media are gasified to absorb heat. Heat flows to the heat exchanger with the working media and dissipated. Later, working media are cooled into liquid which then returns to the reservoir. The reservoir realizes temperature control under the cooperation of heating by the temperature control loop and cooling of backflow. Liquid returns to the position in front of the pump after flowing through the reservoir and the filter. In this way, a closed circulation is formed. During operation of the system, the absolute pressure transducer is put at the entrance of the reservoir to measure pressure of the reservoir. The differential pressure transducers are set at two ends of the pump to measure lifts of the pump. The Coriolis mass flowmeter is put in front of the pump to measure flow rate of the liquid-phase working media in the system. The simulation apparatus and physical picture of the testing system are shown in Fig.4 and Fig.5, respectively.
Fig. 3 Working principle of the mechanical pump performance testing platform

Table 2 Functions of components of the mechanical pump performance testing platform

| Parameters                     | Functions                                                              | Technological parameters |
|-------------------------------|------------------------------------------------------------------------|--------------------------|
| Mechanical pump               | Power source                                                          | 1–2g/s                   |
| Reservoir                     | Controlling evaporating temperature in the loop                       | 0.02–0.05 MPa            |
| Absolute pressure transducer  | Storing the loop / providing working media                           | Volume: 180ml            |
| Differential pressure transducer | Measuring pressure at the end of reservoir                          | Range: 0–2MPa            |
| Coriolis mass flowmeter       | Measuring the lift sum of the pump                                   | Range: 0–0.2MPa          |
| Filter                        | Assuring redundancy content of working media in front of the pump     | 30μm                     |
| Evaporators 1–4               | Simulate heats from the heat source                                  | 4×60W                    |
| Plate heat exchanger          | The cold source of the system. It is cooled by an external refrigerator. | Cooling capacity: 500W   |
4. Testing conditions
To test flow rate, lift and input power of the mechanical pump under different rotating speeds, the testing conditions of single-phase operating performances were set (Temperature of the reservoir was controlled at 30℃. Heat loads of the evaporator were all 0W and the temperature of the heat exchanger was controlled at 5℃). Besides, two-phase operating conditions (temperature of the reservoir was controlled at 30℃, and the heat loads were 240W and the temperature of heat exchanger was controlled at 5℃) were set to verify that the pump could be operated normally and stably under the two-phase loop state.

Table 3 Testing conditions and testing items of the mechanical pump

| Testing conditions       | Single-phase performance (5000~15000rpm) | Two-phase continuous operation (heat loads: 240W) |
|-------------------------|------------------------------------------|-----------------------------------------------|
| Testing items           | Different rotating speeds, flow rates, lifts and powers | Two-phase operating state |

5. Test results

5.1 Single-phase operating performances
Variations of flow rate and lifts of the pump with rotating speed are shown in Fig.6 and Fig.7, respectively. When the pump is operating under the specified working condition (rotating speed: 11000rpm), the flow rate of the pump is 2.043 g/s and the corresponding differential pressure is 0.0517 MPa. Under this circumstance, the input power of the pump is 9.92 W (Table 3). These parameters are all superior to the requirements of design indexes.
Fig. 6 Variations of flow rate of the mechanical pump with rotating speed

Fig. 7 Variations of lift of the mechanical pump with rotating speed

Table 4 Performance parameters of the pump under different rotating speeds

| Rotating speed of the pump (rpm) | Flow resistance (MPa) | Flow rate (g/s) | Input power (W) |
|---------------------------------|-----------------------|----------------|-----------------|
| 5000                            | 0.0082                | 0.725          | 3.21            |
| 6000                            | 0.0131                | 0.957          | 3.83            |
| 7000                            | 0.0190                | 1.185          | 4.71            |
| 8000                            | 0.0261                | 1.408          | 5.77            |
| 9000                            | 0.0345                | 1.638          | 6.88            |
| 10000                           | 0.0435                | 1.866          | 8.36            |
| 11000                           | 0.0517                | 2.043          | 9.92            |

5.2 Two-phase operating performances
Under the two-phase operating conditions, temperature of the reservoir was controlled at 30 °C (ambient temperature is 20 °C). The total heat dissipation power was 240W and the rotating speed of the pump was 7000 rpm. It can be seen from Fig.8 that the heat source on the evaporator 1 is turned on before the pump is started to assure that the evaporator 1 is in the two-phase state. This can prevent overheating in the operation process. When the pump and other heat sources are turned on simultaneously, all four evaporators enter into the two-phase state and temperatures are very consistent. At this moment, temperatures of all four evaporators were 32±0.5 °C, while the temperature of the
reservoir was 30±0.5℃, showing a difference of 2℃. Moreover, the input power of the mechanical pump when it transfers 240W heat was only 4.71W, which reflected the very high energy efficiency ratio of the pump during heat transmission.

![Fig.8 Operating temperatures of the reservoir and evaporators under continuous operating state](image1)

In addition, it can be seen from Fig.9 that the lift of the pump is kept fluctuating within the range of 0.18~0.20MPa when the two-phase operating condition of the system is changed into the single-phase condition. This pump is a constant-lift pump. In other words, the lift of pump is kept basically constant when the rotating speed is not changed. The pump adapts to changes of the flow resistance of the system by adjusting the flow rate. This gives MPTL system good temperature control stability when the two-phase loads change.

![Fig.9 Operating pressure at inlet and outlet of the pump under the two-phase operating state](image2)

It can be seen from Fig.10 that in early startup of the pump, the flow rate of the system fluctuates greatly, ranging 0.1~0.66g/s. However, this fluctuation range is changed to 0.36~0.56g/s after the two-phase state tends to be stable. The system is changed from two-phase state to the single-phase state after the unloading of 240W heats, which increases the flow rate of the system by 1.2g/s. The flow rate of the single-phase system is stable and superior to that of the two-phase system.
6. Environmental adaptation verification

Five of same mechanical pumps were chosen to assess the environments for vibration test, thermal vacuum test and thermal circulation test. Experimental processes are shown in Fig.11~13. In addition, performances of the pumps before and after the vibration test and after the thermal vacuum circulation test were investigated. Test results are shown in Table 5. This proves that the pump can keep basically consistent performances before and after the environmental adaptation verification, indicating that the pump can meet requirements of indexes under service environments.

![Fig.11 Physical pictures of the vibration test](image1)
![Fig.12 Physical pictures of the thermal vacuum test](image2)
![Fig.13 Physical pictures of the heat circulation test](image3)

| Pump | Performance parameters at rated working points | Variation rate ≤5% | Conclusions |
|------|--------------------------------------------------|---------------------|-------------|
|      | Before the vibration test | After the vibration test | After the thermal vacuum test |                          |
|      | Lift (MPa) | Flow rate (g/s) | Lift (MPa) | Flow rate (g/s) | Lift (MPa) | Flow rate (g/s) |                          |
| 01   | 0.063 | 2.25 | 0.064 | 2.22 | 0.064 | 2.24 | 1.54% | Qualified |
| 02   | 0.065 | 2.21 | 0.066 | 2.27 | 0.066 | 2.25 | 2.72% | Qualified |
| 03   | 0.067 | 2.29 | 0.066 | 2.33 | 0.066 | 2.33 | 1.75% | Qualified |
| 04   | 0.066 | 2.35 | 0.066 | 2.34 | 0.066 | 2.33 | 0.86% | Qualified |
| 05   | 0.065 | 2.333 | 0.064 | 2.29 | 0.065 | 2.31 | 1.75% | Qualified |
| 01   | 0.063 | 2.25 | 0.064 | 2.22 | 0.064 | 2.24 | 1.54% | Qualified |
7. Conclusions
(1) The proposed aerospace mechanical pump can meet requirements on designed indexes in term of flow rate, lift and power consumption.
(2) The mechanical pump is applied to a two-phase system and it can transfer 240W heat by using 4.71W input power only. It has the higher heat transmission efficiency compared to the single-phase fluid loop system.
(3) This mechanical pump is a constant-lift pump and it can bring a better temperature controlling stability for MPTL system. This is beyond the capability of gear pump.
(4) The pump can meet technological indexes in vibration, vacuum and heat circulation environments.

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