Applied Thermal Engineering 68 (2014) 1–9

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Transient behaviors of loop heat pipes for alpha magnetic spectrometer cryocoolers

Naihua Wang[a], Zheng Cui[a], Joseph Burger[b], Lin Cheng[a,*]

[a] Institute of Thermal Science & Engineering, Shandong University, Jinan 250061, China
[b] Laboratory for Nuclear Science, Massachusetts Institute of Technology, Boston, MA 02139, USA

HIGHLIGHTS

- Transient behaviors of LHPs for AMS cryocoolers have been investigated in the large space simulator.
- Mechanism of physical process during LHP startup has been analyzed.
- Effect of degree of liquid filling in the compensation chamber on LHP startup characteristics has been studied.
- Conditions for temperature oscillation have been revealed.

ARTICLE INFO

Article history:
Received 21 November 2013
Accepted 20 March 2014
Available online 28 March 2014

Keywords:
Loop heat pipe
Bypass valve
Transient behavior
Startup
Temperature oscillation

ABSTRACT

Startup and oscillation characteristics of loop heat pipes (LHPs) for alpha magnetic spectrometer (AMS) cryocoolers during thermal vacuum and thermal balance (TVTB) testing were determined. The mechanism of the physical process during LHP startup was analyzed in detail. Factors including liquid/vapor distribution in the evaporator, filling rate of the compensation chamber, and LHP elevation were investigated. Startup proved easier when vapor was present in the vapor grooves, whereas vapor in the evaporator core had an adverse effect. When the vapor grooves are liquid-filled, the startup process can be divided into three stages: heating of LHP components before superheating establishes, nucleate boiling after superheating is satisfied, and successful loop circulation. When the vapor grooves are vapor-filled, there are only two stages in LHPs: nucleate boiling and loop circulation establishment. Examination of the effect of compensation chamber filling rate on startup characteristics showed that reverse flow occurred when vapor was present in the compensation chamber and startup proved difficult. Filling rate of the compensation chamber should be sufficient to provide thorough wetting of the capillary structure, as otherwise wick dry-out may occur and prevent LHP startup. Temperature oscillations normally occurred at high sink temperature and/or heat load. Inclusion of a bypass valve was an effective measure to suppress temperature oscillations, because vapor at the condenser was not saturated when the bypass valve was open.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

The alpha magnetic spectrometer (AMS) is one of the greatest scientific projects, with the main aim of searching for dark matter and anti-matter [1]. AMS consists of a magnet and six ultrahigh accuracy detectors, namely a transition radiation detector (TRD), a silicon tracker (Tracker), a time of flight (TOF), a ring-imaging Cerenkov detector (RICH), an electromagnetic calorimeter (ECAL), and an anticoincidence counter (ACC). AMS uses four Stirling cryocoolers (CC) to extract parasitic heat from the shield around the helium-cooled magnet. Loop heat pipes (LHPs), with propylene as the working fluid, transfer heat from the cryocoolers. Each cryocooler has two redundant LHPs, a left and a right LHP, and the heat dissipates from the LHPs to deep space through condensers integrated with the dedicated zenith radiator (Fig. 1). Each LHP consists of an evaporator connected to the cryocooler, a compensation chamber, liquid line, vapor line, bypass valve, bypass line, and a condenser (Fig. 2). LHPs with bypass valves work to ensure the cryocooler performs normally within its temperature limits: [−20 °C, +40 °C]. Xin et al. [2] built a model of LHPs for AMS cryocoolers with SINDA/FLUINT, while Wang et al. [3] studied the bypass valve characteristics of LHPs experimentally. However, there

---

[*] Corresponding author. Tel./fax: +86 0531 88399598.
E-mail address: cheng@sdu.edu.cn (L. Cheng).

http://dx.doi.org/10.1016/j.applthermaleng.2014.03.047
1359-4311/© 2014 Elsevier Ltd. All rights reserved.

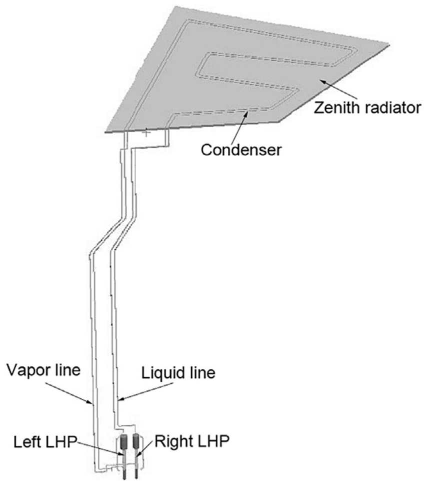
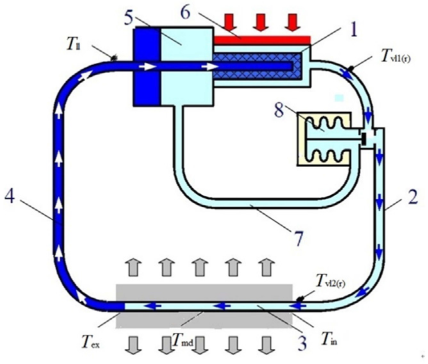


Fig. 1. Loop heat pipe layout. 1. Evaporator; 2. Vapor line; 3. Condenser; 4. Liquid line; 5. Compensation chamber; 6. Cryocooler body; 7. Bypass line; 8. Bypass valve.

is less knowledge of the transient behaviors of the LHPs for AMS cryocoolers.

Startup of an LHP is the most complex transient phenomenon. Redistribution and circulation of fluid in the loop occur together with phase changes such as nucleate boiling, evaporation, and condensation. Prior conditions play an important role in startup. Factors such as heat load, elevation and liquid/vapor distribution in the evaporator have been investigated [4–19]. Liquid/vapor distribution in the LHP was considered the most important factor.

Zhang et al. [4] investigated the effects of heat load on the LHP startup characteristics in ambient condition. They found that high heat load helps startup. Singh et al. [5] found that the vapor generation process inside the evaporation zone is very slow which increases the startup time at low heat load. Chernysheva et al. [6] numerically investigated the transient process of heat and mass transfer in a cylindrical evporator of a loop heat pipe during startup. Effect of heat load on the startup an LHP was also analyzed numerically by Bai et al. [7]. They found that there is a minimum heat load to realize an LHP startup. Joung et al. [8] found that the mimimum startup heat load for a flat evaporator loop heat pipe was 40 W and the LHP showed sleeping mode operation at a very low heat load of 10 W. Wang [9] suggested that it is benificial to improve the startup characteristics if a heat sink is installed on the compensation chamber.



1. Evaporator; 2. Vapor line; 3. Condenser; 4. Liquid line;
5. Compensation chamber; 6. Cryocooler body;
7. Bypass line; 8. Bypass valve

Fig. 2. Schematic diagram of loop heat pipe.

An adverse elevation means the evaporator is above the condenser [10]. Because the saturated pressure drop is related to the saturated temperature difference across the wick in accordance with the Clausius–Clapeyron equation, the additional pressure at adverse elevations required to pump the return liquid fluid against gravity will increase the temperature differential across the wick required for startup, hence delaying startup [11]. Chen et al. [12] found that elevations greatly influence the LHP startup characteristics owing to liquid/vapor distribution variation. Joung [8] suggested LHP startup characteristics may be affected by the coupling effects of the hydrostatic pressure and the liquid/vapor distribution because of the changing of relative position between the LHP components. However, Zhang et al. [4] found that the effect of adverse elevation was to increase the temperature overshoot and startup time when vapor existed in the vapor grooves, while decreased the temperature overshoot and start-up time when the vapor groove was filled with liquid.

Maydanik [13] suggested there are four types of vapor/liquid distribution situation before startup: (1) Both the vapor grooves and the evaporator core are flooded with liquid; (2) the vapor grooves are filled with liquid while the evaporator core contains vapor; (3) vapor is present in the vapor grooves and liquid completely fills the evaporator core; and (4) vapor is present in both the vapor grooves and the evaporator core. If the vapor grooves are completely liquid-filled, superheating is required to initiate nucleate boiling. Otherwise, if the vapor grooves are vapor-filled, liquid evaporates without superheating once the heat load is applied. If the evaporator core is liquid-filled, heat leakage from the evaporator to the compensation chamber is minimal. However, if vapor is present in the evaporator core, a much larger heat leakage is realized. Refs. [4] and [10] verified the LHPs startup characteristics experimentally under all types of situations. Startup characterisitics of a miniature LHP under type (1) and (4) conditions were also verified in Ref. [12].

However, the effect of the liquid filling rate of the compensation chamber has not yet been clearly described and the detailed mechanism involved in the physical process during startup has not been fully defined.

The LHP operating temperature is dependent on the load and the sink temperature. As the operating conditions change, the evaporator temperature will change during the transient phase and reach a new steady state. However, under certain conditions, the LHP never really reaches a steady state, but instead displays oscillatory behavior [5,8,12,14,15,19–22]. Three types of temperature oscillation have been reported [12,18]. The first type is ultra-high frequency temperature oscillations lasting seconds, caused by formation of liquid slugs in the condenser or the vapor line. This type of temperature oscillation is not significant due to the very low oscillation amplitude. The second type is high frequency temperature oscillations lasting seconds to minutes, caused by the inability of the vapor front to find a stable position about the condenser exit. The amplitude of temperature oscillations in the liquid line can be higher than 10 K, whereas the amplitude in the evaporator is very small, of the order 1 K or less. The third type is low frequency temperature oscillations lasting hours, which may appear with specific conditions such as large evaporator thermal mass, low heat load and cold sink temperature. The amplitude can be as high as tens of K. A transient model of loop heat pipes has been developed by Launay et al. [21] to simulate the oscillation behavior. Two different temperature fluctuation patterns have been simulated: the “high frequency low amplitude” and the “low-frequency high amplitude”. Their characteristics (in frequency and amplitude) are of the same order as the ones observed during LHP tests available in

Download English Version:

https://daneshyari.com/en/article/646224

Download Persian Version:

https://daneshyari.com/article/646224

Daneshyari.com